DECEMBER 1910 VOL. 32 No. 12

THE JOURNAL

OF

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS

PUBLISHED AT 2427 YORK ROAD . . . . .BALTIMORE, MD.
EDITORIAL ROOMS, 29 WEST 39TH STREET . . . . .NEW YORK

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THE JOURNAL is published monthly by The American Society of Mechanical Engineers. Price, one dollar per copy—fifty cents per copy to members. Yearly subscriptions $7.50; to members, $5.

Entered at the Postoffice, Baltimore, Md., as second-class mail matter under the act of March 3, 1879.

The professional papers contained in The Journal are published prior to the meetings at which they are to be presented, in order to afford members an opportunity to prepare any discussion which they may wish to present.

The Society as a body is not responsible for the statements of facts of pinio ns advanced in papers or discussions. C55

THE JOURNAL

OF

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS

VOL. 32 DECEMBER 1910 NUMBER 12

COMMITTEE ON MEETINGS OF THE SOCIETY IN NEW YORK

At a meeting of the membership held on October 31, nominations were made and approved by the Committee on Meetings for a Committee on Meetings of the Society in New York, similar to the committees in Boston, St. Louis and San Francisco. The committee chosen consists of Prof. Walter Rautenstrauch, Chairman, Frederick A. Waldron, Treasurer, Fred. H. Colvin, Edward Van Winkle and Roy V. Wright. This is one of the most important developments of the year, as it places for the first time in the history of the Society all the meetings on the same basis. This committee will also form the nucleus of the committee to conduct the social features of the Annual Meeting. The duties of the committee in New York will not in any way overlap those of the Committee on Meetings of the Society, which will have jurisdiction, as formerly, over all the meetings in general and of the Annual and Spring meetings in par ticular.

THE ANNUAL MEETING

The Thirty-second Annual Meeting of the Society will be held in the Engineering Societies Building, 29 West 39th Street, New York, December 6–9, 1910.

A professional program with papers of unusual variety and merit has been arranged by the Meetings Committee, Willis E. Hall, Chairman, and provides for five sessions, to occupy the morning and afternoon of both Wednesday and Thursday, leaving Friday free for excursions or other entertainment. At the Wednesday morning session, following the presentation of reports and other business, there will be an account of the Joint Meeting in England by the Secretary; and also a paper on the Transmission of Heat in Surface Condensation by George A. Orrok. On Wednesday afternoon a session on Steam Engineering will be held; and on Thursday there will be a session in the morning on miscellaneous topics, with simultaneous meetings in the afternoon, one on machine shop topics, and the other that of the Gas Power Section. Luncheon will be served on both Wednesday and Thursday to members and guests.

ENTERTAINMENT

The entertainment features will be in charge this year of the Committee on Meetings of the Society in New York, Walter Rautenstrauch, Chairman, Frederick A. Waldron, Treasurer, F. H. Colvin, Edward Van Winkle and Roydon V. Wright, assisted by sub-committees. A number of excursions have been planned for Friday morning and afternoon, including the New York Public Library, not yet open to the general public, Nelson Goodyear, Inc., with an exhibit of autogenous welding, Pond Machine Tool Company, Thompson-Lovelace Aeroplane Company, Robins Dry Dock, New York Telephone Company's Exchange, and the Navy Yard in Brooklyn. There will also be opportunities throughout the convention to visit the Metropolitan Building, the Hudson and Manhattan Power House, the Interboro Power House, the Hill Publishing Company, New York Edison Company's waterside power plant, the Franco-American Soup Company, and the Sims Magneto Company.

A Ladies' Reception Committee, under the chairmanship of Mrs. Herbert Gray Torrey, will arrange for the entertainment of the

guests of the membership in a manner similar to that of previous years. Tea will be served on Tuesday, Wednesday and Thursday afternoons in the Ladies' Headquarters in the rooms of the Society, and various trips to points of interest, including shops and hotels, will be made under competent guides.

RECEPTION AND EVENING MEETINGS

The opening session on Tuesday evening will be the occasion of the annual address of the President, and of the report of the Tellers of Election of Officers. This will be followed by a reception by the President and President-elect in the rooms of the Society. On Wednesday evening there will be a reunion of the membership at the Hotel Astor, with dancing and refreshments. Boxes will be available for those who do not desire to participate in the dancing.

Mr. and Mrs. Westinghouse will receive the members and guests at the Hotel St. Regis from four to six o'clock on Thursday afternoon.

The lecture on Thursday evening, by Dr. Georg Kerschensteiner on Industrial Continuation Schools of Munich, will be one of unusual interest because of Dr. Kerschensteiner's wide reputation as an educator and brilliant lecturer and his own interest in the important subject of the training of workmen. This lecture, although it appears on the program of the Annual Meeting, is one arranged through the courtesy of the National Society for the Promotion of Industrial Education, the Society, together with the American Institute of Electrical Engineers and the American Institute of Mining Engineers, having been invited by the National Society for the Promotion of Industrial Education to act as joint hosts on this occasion.

HEADQUARTERS

The headquarters will be established in the foyer on the first floor of the Engineering Societies' Building. Members and guests are requested to register immediately upon their arrival and receive a badge and program. Railroad certificates should be presented at that time for validation. A writing room will be provided on the first floor opposite the entrance fully equipped for the use of members. There is also a telephone exchange with several booths on the first floor adjoining the elevators, providing ample facilities for quick service.

MEMBERS REGISTER

Two editions of the printed Members Register will be issued. The first will include the names of those registered before 9 p.m. Tuesday, and will be distributed at the morning session on Wednesday. The second edition will contain the names of those registered before 10 p.m. on Wednesday. It will be distributed at the morning session on Thursday.

RAILROAD TRANSPORTATION

Arrangements for hotel, transportation and Pullman car accommodations should be made personally.

For members and guests attending the Annual Meeting in New York, December 6-9, 1910, the special rate of a fare and three-fifths for the round trip, on the certificate plan, is granted when the regular fare is 75 cents and upwards, from territory specified below.

a Buy your ticket at full fare for the going journey, between December 2 and 8 inclusive, and get a certificate, *not a receipt*, securing these at least half an hour before the departure of the train.

b Certificates are not kept at all stations. If your station agent has not certificates and through tickets, he will tell you the nearest station where they can be obtained. Buy a local ticket to that point and there get your certificate and through ticket.

c On arrival at the meeting, present your certificate to S. Edgar Whitaker, office manager, at the Headquarters. A fee of 25 cents will be collected for each certificate validated. No certificate can be validated after December 9.

d An agent of the Trunk Line Association will validate certificates, Dec. 7, 8, 9. No refund of fare will be made on account of failure to have certificate validated.

e One-hundred certificates and round trip tickets must be presented for validation before the plan is operative. This makes it important to show the return portion of your round trip ticket at Headquarters.

f If certificate is validated, a return ticket to destination can be purchased, up to Dec. 13, on the same route over which the purchaser came, at three-fifths the rate.

This special rate is granted only for the following:

Trunk Line Association:

All of New York east of a line running from Buffalo to Salamanca, all of Pennsylvania east of the Ohio River, all of New Jersey, Delaware and Maryland; also that portion of West Virginia and Virginia north of a line running through Huntington, Charleston, White Sulphur Springs, Charlottesville, and Washington, D. C.

New England Passenger Association, except Eastern Steamship Co. and Metropolitan Steamship Co.

Maine, New Hampshire, Vermont, Massachusetts, Rhode Island and Connecticut.

Central Passenger Association:

The portion of Illinois south of a line from Chicago through Peoria to Keokuk and east of the Mississippi River, the States of Indiana, and Ohio, the portion of Pennsylvania and New York north and west of the Ohio River, Salamanca and Buffalo, and that portion of Michigan between Lakes Michigan and Huron.

Eastern Canadian Passenger Association:

Canadian territory east of and including Port Arthur, Sault Ste. Marie Sarnia and Windsor, Ont.

PRELIMINARY PROGRAM

TUESDAY, DECEMBER 6

8.30 p.m.

Presidential Address, George Westinghouse.

Report of Tellers of Election of Officers.

President's reception in the rooms of the Society. All members and guests invited. Cards of admission upon application.

Music and refreshments, Chas. W. Aiken, Chairman Sub-Committee in charge.

WEDNESDAY, DECEMBER 7

10 a.m.

Reports of Council, standing and special committees, and tellers of election of membership. New business.

The Joint Meeting in England: Report by the Secretary.

The Transmission of Heat in Surface Condensation, George A. Orrok.

2 p.m.

Combustion and Boiler Efficiency, Edw. A. Uehling.
Automatic Control of Condensing Water, B. Viola.
Test of a 10,000-kw. Steam Turbine, Sam. L. Naphtaly.
Test of a 9000-kw. Turbo-Generator Set, F. H. Varney.
Notes on the Value of Napier's Coefficient with Superheated Steam, Isaac Harter, Jr.

9 p.m.

Reunion of the membership in Hotel Astor. Dancing and Refreshments.
Robert S. Allyn, Chairman Sub-Committee in charge of Reunion.

THURSDAY, DECEMBER 8

10 a.m.

A New Theory of Belt Driving, Selby Haar.
Stresses in Connecting Rods, W. H. Herschel.
Operating Conditions of Passenger Elevators, Reginald P. Bolton.
Modern Shoe Manufacture, M. B. Kaven and J. B. Hadaway.

SIMULTANEOUS SESSIONS, 2 p.m.

MACHINE SHOP

The Field for Grinding, C. H. Norton.
Precision Grinding, W. A. Viall.
Modern Grinding Methods, B. M. W. Hanson.

GAS POWER SECTION

Business Meeting.
First Large Gas Engine Installation in American Steel Works, E. P. Coleman.
Other Gas Power papers as assigned.

Reception to members and guests by Mr. and Mrs. Westinghouse, Hotel St. Regis, 4 to 6 p. m.

8.15 p.m.

Address: Industrial Continuation Schools of Munich, Dr. Georg Kerschensteiner, Superintendent of Schools, Munich, Bavaria.

FRIDAY, DECEMBER 9

Excursions to points of engineering interest.

COMING MEETINGS

MEETING IN ST. LOUIS, DEC. 10

The next monthly meeting of the Society at St. Louis will be held on the evening of December 10, the Engineers Club of St. Louis coöperating.

MEETING IN BOSTON, DEC. 16

At the meeting of the Society in Boston for December a paper will be presented by Samuel B. Fowler, Consulting Engineer, Boston, on Terminal Facilities for Handling Freight. The Boston Society of Civil Engineers and the Boston Section of Institute of Electrical Engineers willl coöperate.

REPORT OF MEETINGS

MEETING IN NEW YORK, NOVEMBER 9

The New York monthly meeting for November was held on the ninth, the day following the regular time for the meeting, owing to Election Day coming on that date. The attendance was 163.

The first half of the session was devoted to a paper on the Rotary Kiln by Ellis Soper, Mem.Am.Soc.M.E., of Detroit, Mich., which was read by Prof. R. C. Carpenter of Ithaca, New York, Vice-President Am.Soc.M.E., in the absence of the author. Following this paper was an address on the Panama Canal by Charles Whiting Baker, Vice-President Am.Soc.M.E., editor of Engineering News. Mr. Baker discussed the methods used in carrying on the construction work at the canal, illustrating his talk with pictures taken at the time of his visit in 1909, when accompanying the engineering commission appointed by President Roosevelt. Mr. Baker said that the Canal is to be regarded as a problem in transportation as, in fact, practically everything is a problem of this type. Things are not made or manufactured, but one sort of material is merely taken from one place and put into another. The digging of the canal is easier and simpler than the carrying away to a distance of several miles of the material dug out by the great steam shovels, which remove 5 cu. yd. at a movement. But even this is cheaper than to pile the material on the high banks of the canal.

A greater problem, even, than this one of the removal of earth is the caring for the big working force of 30,000 laborers and 5000 skilled workmen, comprising over a score of different nationalities and all social grades. Moreover, everything needed to build the canal,—tools, machines, cars, locomotives, lumber,—and to make comfortable the great force of men and their families, had to be brought 2000 miles.

The engineers at the Canal had taken up many of their burdens, not through choice, but of necessity, for conditions had to be met as they arose, and they should rather be honored than criticised for their achievements, by none more than by their professional brethren.

MEETING IN BOSTON, NOVEMBER 10

The first monthly meeting of the Society in Boston for the present season was held on the evening of November 10 in the auditorium of the Edison Company, with the Boston Society of Civil Engineers and the Boston Section of the American Institute of Electrical Engineers coöperating The attendance was 150.

After a brief business session, at which a nominating committee to select a new Committee on Meetings of the Society in Boston was appointed, a topical discussion on Smoke Abatement was opened by Dwight T. Randall, Mem.Am.Soc.M.E., who made a statement of the case as applied to New England. He was followed by E. G. Bailey, Frederick H. Keyes, Charles H. Manning, Henry Bartlett, George H. Barrus, John T. Hawkins and C. H. Bigelow. Mr. Randall said that ordinances making it unlawful to produce smoke are not in themselves effective and that results can be accomplished only by recognizing the difficulties and overcoming them along engineering lines. Leading up to the all-important question of the combustion of bituminous coal, he discussed the relation of volatile matter to smoke and the effect upon combustion of ash, moisture and the size of the coal. He discussed the design of furnaces for bituminous coal, including brick work, baffles, arches, etc., and questions of air supply, the prevention of smoke during hand-firing and the use of stokers. The mere installation of the latter, he said, will not insure smokeless combustion, but the questions of draft and its regulation and other engineering conditions must be considered. Numerous tests were presented of the performance of boilers with different fuels.

MEETING IN ST. LOUIS, NOVEMBER 12

A meeting of the St. Louis members of the Society was held on Saturday evening, November 12, at the Mercantile Club. At the conclusion of dinner, the meeting was called to order by Wm. H. Bryan, Chairman of the Committee on Meetings in St. Louis. On motion the present committee, consisting of Wm. H. Bryan, M. L. Holman, E. L. Ohle, F. E. Bausch and R. H. Tait, was reëlected for one year, subject to the approval of the Meetings Committee of the Society and of the Engineers' Club of St. Louis, with whom meetings are usually held. The method heretofore followed in the conduct of local meetings was approved, and it was voted that for the present the meetings continue to be conducted jointly with the Engineers' Club of St. Louis. A general discussion of ocal business followed.

MEETING OF THE COUNCIL

A meeting of the Council was held on the afternoon of Wednesday, November 9, 1910, in the rooms of the Society, and was called to order at 3.30 p.m. by the President. There were present, George Westinghouse, Chas. Wallace Hunt, Fred. W. Taylor, Chas. Whiting Baker, George M. Bond, R. C. Carpenter, E. D. Meier, Fred. M. Whyte, J. Sellers Bancroft, James Hartness, I. E. Moultrop, H. G. Reist, Wm. H. Wiley and the Secretary. Regrets were received from W. F. M. Goss, H. L. Gantt, C. E. Billings, Oberlin Smith and Robert W. Hunt.

The minutes for the meeting of October 11 were read and approved.

The President appointed Chas. Wallace Hunt, Chas. Whiting Baker and J. Sellers Bancroft tellers to count the Ballots for Life Membership of W. F. Mattes of Scranton, Pa., and S. B. Whiting of Cambridge, Mass., under the provisions of C 23 and B 36 of the Constitution and By-Laws. The President later announced their unanimous election.

The Secretary announced the following deaths: Clay Belsley, Peoria, Ill., F. B. Hall, New York, Washington Jones, Philadelphia, Pa., O. S. Shantz, Buffalo, N. Y., F. M. Wheeler, NewYork, A. Wilkinson, Bridgeport, Pa.

Voted: To accept the resignations of John S. Naylor, Henry Brewer, Geo. W. Heald, Jr., Gustav Kaffenberger, Fred Nolde, O. S. Porter, Fred. W. Gordon, George Berna, Jarred E. Jones.

Announcement was made of the appointment by the President of a Public Relations Committee, under the provisions of C 45, consisting of James M. Dodge, Chairman, Robert W. Hunt, D. C. Jackson, J. W. Lieb, Jr., Fred J. Miller.

Voted: To accept the reports of the standing committees presented by the Secretary and that so much of these reports be printed in the next number of The Journal as in the discretion of the Secretary may seem proper.

The Secretary read a letter from the Third Assistant Postmaster General granting extension of time.

Voted: In accordance with the recommendation of the Publication Committee to appoint Wm. H. Wiley, Treasurer, and Calvin

W. Rice, Secretary, a committee to confer with the Post Office Department in Washington with a view to establishing our claim for second class entry of The Journal.

Voted: To refer to the Publication Committee with the suggestion that they again confer with Vice-President Baker and report to the Council.

The Secretary presented communications to the Council in connection with the ballots for officers of the Society.

It was also announced that a committee of members was in the reception room and desired to be permitted to present the same matter to the Council in person; a statement was made of the action which the Secretary had taken and of the authority under which he had acted. The following committee of members was then invited to the Council room: Messrs. H. F. J. Porter, H. H. Suplee, E. G. Spilsbury, Wm. H. Boehm, H. L. Aldrich. Mr. Porter presented a letter to the Council. A full discussion followed.

Voted: To refer the matter to the Executive Committee with the request that that Committee take advice of counsel and report at an adjourned meeting of the Council.

Voted: To adjourn subject to call of the Executive Committee.

SPECIAL MEETING

An adjourned meeting of the Council was held on the afternoon of Wednesday, November 16, 1910, in the rooms of the Society, and was called to order at 3.30 p.m. by Vice-President Meier. There were present, George M. Bond, Chas. Whiting Baker, James Hartness, F. R. Hutton, Jno. R. Freeman, E. D. Meier, Jesse M. Smith, H. G. Reist, Fred. W. Taylor, Fredk. M. Whyte and the Secretary. Regrets were received from I. E. Moultrop and J. Sellers Bancroft.

The minutes of the meeting for November 9 were read and approved.

Vice-Chairman Chas. W. Baker read the report of the Executive Committee on the matter of the Ballot for Officers for the year 1910 1911.

Voted: That the report of the Executive Committee be received and placed on file.

The Council then took up seriatim the resolutions embodied in this report, with the following action:

Voted: That after consideration of the communication of November 7, the Council deems it unwise to interfere with the election now

in progress and directs that it proceed in the same manner in which it has been conducted in previous years.

Voted: To adopt the following rule:

35 The tellers of election in counting the ballots for officers shall consider the ballot for an officer as valid, provided the intent of the voter as to that particular office is clear, even though his ballot as to candidates for another office may for any reason be invalid.

Voted: That the Council approves the form of ballot distributed by the members and decides that it is in conformity with the Constitution and By-Laws of the Society in particular with B 14, B 29 and B 30.

Voted: That in view of the opinion of our legal advisor, the ballots which have been distributed are in accordance with the previous precedents of the Society and are deemed to be legal ballots.

Voted: That what appears to be a discrepancy between the Charter of 1907 and the existing By-Laws of the Society in connection with the dates of the Annual Meeting of the Society be referred to the Committee on Constitution and By-Laws for consideration and report previous to the Annual Meeting of 1910.

Voted: That a summary be made of the action taken by the Council on the communications received by it in connection with the Ballot for Officers, such summary to be sent to each member who makes inquiry concerning the ballot, and also to the Special Nominating Committee, and that a summary be included in the account of the proceedings of the Council as is regularly published in The Journal.

Voted: On recommendation of the Chairman of the Committee on Student Branches, that the formation of such student branch at Rensselear Polytechnic Institute be approved.

Voted: To approve the formation of a student branch at the Washington University, St. Louis, Mo.

Voted: That the Honorary Secretary be requested to make a report to the Council of the Joint Meeting of the Society held in England during the past summer.

Voted: To adjourn to Tuesday, December 6, at 2.30 p.m. and that 2.30 p.m. be the regular hour for Council meetings until further notice.

STUDENT BRANCHES

The following officers have been elected at the Brooklyn Polytechnic Institute for the year 1910–1911: Chairman, A. L. Palmer, Vice President, Mr. Siebert, Secretary, R. C. Ennis, Treasurer, Henry Priester. At the meeting on October 15, Lester G. French, Editor of The American Society of Mechanical Engineers, spoke to the society on Technical Publications. At the November 5 meeting Mr. Foster of the New York School of Automobile Engineers addressed the members.

The Purdue University Student Branch was addressed on November 2 by Prof. H. O. Garman, of the Civil Engineering Department of the University, on Railway Signalling Devices; and on November 16 by E. C. Clarage of the Columbia Tool Steel Company upon Tool Steel.

At the November meeting of the Sibley College Student Branch, David S. Wegg, Jr., Jun.Mem.Am.Soc.M.E., was elected corresponding secretary to succeed Prof. C. F. Hirshfield, resigned.

On Tuesday, November 1, I. E. Moultrop, Mem.Am.Soc.M..E, lectured before the Stevens Engineering Society on The Design and Construction of a Central Power Station, giving the latest ideas and practice which govern the location and equipment of such a plant, illustrated by a number of slides, including a remarkable series of photographs of Boston taken from the top of the tall chimney of the central station. On November 15, Dr. James P. Haney, lecturer and director of art in the high schools of New York City, addressed a large audience on the advantages of a knowledge of the principles of art in the field of engineeering.

At the first regular meeting of the University of Cincinnati on October 21, a talk was given by A. L. DeLeeuw, Mem.Am.Soc.M.E., chief engineer of the Cincinnati Milling Machine Company, on Milling Cutters. This was illustrated by a large number of lantern slides.

At the October meeting of the University of Illinois, A. Bement, Mem.Am.Soc.M.E., addressed the membership on The Coal Problem.

At a meeting of the Wisconsin Student Branch held on November 3, two new students were admitted as members. J. S. Langwill presented a paper upon Machines for the Spinning Industry and E. F. Week gave a talk upon a Projected Water Power Plant in the West.

NECROLOGY

FREDERICK BELLOWS HALL

Frederick Bellows Hall, Member of the Society, was born October 18, 1868, at Boston, Mass. He received his technical education at the Massachusetts Institute of Technology and after graduation in 1890, was employed by the West End, now known as the Boston Elevated Street Railway Company, as draftsman on the design of their Central Power Station. The following year as chief draftsman with F. S. Pearson, consulting engineer, Boston, he designed various power stations, among them the Brooklyn City Railroad Company, Brooklyn, N. Y., Montreal Street Railway Company, Montreal and Quebec, St. Johns Street Railway Company, St. Johns, N. B., Halifax Street Railway and Lighting Company Halifax, N. S., Chelsea Gas Lighting Company, Chelsea, Mass., Charlestown Gas Company, Boston, Mass., Lawrence Gas Lighting Company, Brighton, Mass. During this time he also acted as superintendent of construction of power stations for the Baltimore Electric Refining Company, Baltimore, Md., Dover Lighting and Power Company, Dover, N. H., and the Portland Street Railway Company, Portland, Me. He was subsequently employed as assistant chief engineer of the Brooklyn City Railroad (Brooklyn Rapid Transit) Company in charge of the design and construction of their Kent Avenue, Southern and Ridgewood Power Stations; and in 1894 had charge of the design and construction of the main power station of the Consolidated Traction Company (now the Public Service Corporation of New Jersey), Newark, N. J. In 1895 he engaged in the design of apparatus for the manufacture of sulphuric acid, and in the following year was employed by J. H. Bickford as consulting engineer in charge of the design of a power station for the Steinway Railway Company. In the same year he became treasurer and general manager of the North Sydney Mining and Transportation Company, Sydney, Cape Breton, N. S., leaving there to become chief draftsman for the Riter-Conley Manufacturing Company of Pittsburgh in charge of the design of blast furnace and steel works for the Dominion Iron and Steel Company of Cape Breton.

From 1899 to 1901 he was engaged on the design and construction of the main power station of the Manhattan Elevated Railway Company, New York City, and at the time of his death, October 27, 1910, was in the employ of W. E. Baker and Company.

WASHINGTON JONES

Washington Jones, who died on July 30, 1910, was born in Philadelphia, February 22, 1822, and became an apprentice at the works of Merrick and Agnew at fifteen years of age—the first apprenticeship taken in that establishment, it is said. His industry and capacity were attested by his advancement to positions of responsibility there and in several other engineering works of Philadelphia, such as the Southwark Foundry, Merrick and Towne, and the Penn Treaty Works of the Neafie and Levy Ship and Engine Building Company. He was associated with the Port Richmond Iron Works of the I. P. Morris Company as constructing engineer from 1856 to 1891 with a brief interruption of a few years at the Southwark Foundry, when he bore an important part in the productions of that establishment during the Civil War.

Mr. Jones had been a member of the Society since 1880. He was also an honorary member and past president of the Engineers' Club of Philadelphia, a member of the American Society of Civil Engineers and the oldest surviving member of the Franklin Institute of which he was vice-president at the time of his death.

STILLMAN W. ROBINSON

Stillman Williams Robinson, Member of the Society, died October 31, 1910, at his home in Columbus, O. He was born near South Reading, Vt., March 6, 1838, and earned the money to defray the expenses of his early education and to prepare himself for college as an apprentice to the trade of machinist. In 1860 he entered the University of Michigan, making his way to Ann Arbor mostly on foot and meeting his expenses on the way by working as a machinist. From here he was graduated in 1863 with the degree of C.E., having supported himself throughout the college course by skilled instrument making, while there inventing a machine for graduating thermometers, a work in which he was particularly interested. After graduation he entered the government service as assistant engineer in the United States Lake Survey, remaining until 1866 when he

returned to his alma mater as an instructor in engineering. In 1870 he became professor of mechanical engineering and physics in the Illinois Industrial University, now the University of Illinois, establishing the first department of mechanical engineering in this country; and in 1878 was made dean of the College of Engineering. In the same year he was called to Ohio State University as professor of physics and mechanical engineering and occupied that chair until 1895 when he resigned in order to devote his time to his extensive professional interests.

Professor Robinson was the author of a number of important books and papers presented before various societies. He also secured about forty patents, many of which were fundamental and of great value. His inventions were based upon scientific research and mathematical investigation and were the results of skillful study. When the Ohio gas fields were first discovered, the problem of measuring the volume of flow was referred to Professor Robinson and solved by him in his brilliant application of the Pitot tube, resulting in methods now in universal use.

His interest in education was always great and led him in 1890 to organize an association composed of teachers of mechanical engineering which in 1893 developed into the present Society for the Promotion of Engineering Education. His interest in the University of Ohio did not cease with his retirement and he made at various times valuable donations to the equipment of its department of mechanical engineering, finally establishing the Robinson fellowship in engineering as a permanent foundation.

The following minute was adopted by the faculty of the Ohio State University, at its last meeting:

As a man, Professor Robinson was an indefatigable worker. There was no limit to his enthusiasm and ambition in his profession. Personally, he was modest and retiring, never claiming credit for himself though most generous in according it to his associates. He was greatly interested in the work of those around him, impressing his own enthusiasm upon the efforts of both colleagues and students, encouraging, stimulating and rewarding them. His memory and influence will long be felt in the lives of those who follow him and who have taken up his work.

REPORTS OF STANDING COMMITTEES TO THE COUNCIL

REPORT OF THE FINANCE COMMITTEE

After one of the most active years in the history of the Society your Committee is gratified in being able to present a financial report which indicates growth and prosperity financially as well as technically.

Although the current expenses of the Society were larger than in any time in its history, yet as will be seen from the appended reports the current income has met the expenses in full and has enabled us to cancel in this one year all of the extraordinary expenses up to date, due to the Joint Meeting with the Institute of Mechanical Engineers in England the past summer, and also to add to our surplus account. This has been made possible from the fact that our excess of income over expenses for the year was $10,649.41.

It is also interesting to note that at the close of the fiscal year our entire surplus represented by property and accounts receivable was $6,433.56 greater than September 30, 1909.

The Committee regret to record that no specific results have been attained during the year just closed in the direction of reducing our mortgaged indebtedness. The total amount received during the past year to the credit of the land fund was not the equivalent of one-fifth of the interest on the mortgage, thereby making it necessary to look elsewhere to meet this interest charge.

It seems to the Committee that there is an urgent necessity for a strong effort to be made to reduce this mortgaged indebtedness materially each year until it is wiped out, and the interest money thereby made available for the extension of our Society work.

Herewith are given the detailed statements of the financial condition of the Society, together with the reports of Peirce, Struss & Co. of New York, certified public accountants, who have audited the books and accounts, and also a statement of the condition of the various trust funds for the fiscal year.

PEIRCE, STRUSS & CO.
CERTIFIED PUBLIC ACCOUNTANTS
37 Wall Street, New York

October 26, 1910

MR. ARTHUR M. WAITT,
CHAIRMAN FINANCE COMMITTEE
Dear Sir:

In accordance with your instructions, we have audited the books and accounts of The American Society of Mechanical Engineers for the year ended September 30, 1910.

The results of this examination are presented in three exhibits, attached hereto, as follows:

Exhibit A Balance Sheet, September 30, 1910
Exhibit B Income and Expenses for the year ended September 30, 1910.
Exhibit C Receipts and Disbursements for year ended September 30, 1910.

We beg to present, attached hereto, our Certificate to the aforesaid exhibits.

Respectfully submitted,
PEIRCE, STRUSS & CO.
Certified Public Accountants

PEIRCE, STRUSS & CO.
CERTIFIED PUBLIC ACCOUNTANTS
37 Wall Street, New York

October 26, 1910

MR. ARTHUR M. WAITT,
CHAIRMAN FINANCE COMMITTEE
Dear Sir:

Having audited the books and accounts of The American Society of Mechanical Engineers for the year ended September 30, 1910, we hereby certify that the accompanying Balance Sheet is a true exhibit of its financial condition as of September 30, 1910, and that the attached statements of Income and Expenses, and Cash Receipts and Disbursements are correct.

PEIRCE, STRUSS & CO.
Certified Public Accountants

EXHIBIT A

BALANCE SHEET, SEPTEMBER 30, 1910

ASSETS

Equity in Societies Building (25 to 33 West 39th Street)	$353 346.62	
Equity one-third cost of land (25 to 33 West 39th Street)	180 000.00	
		$533 346.62
Library Books	13 000.00	
Furniture and Fixtures	5 000.00	
		18 000.00

New York City 3½% Bonds 1954		
Par $35,000	30 925.00	
Cash in Bank representing Trust Funds	11 356.59	
		42 281.59
Stores including plates and finished publications		11 623.03
Cash in Bank for general purposes	3 611.73	
Petty Cash on hand	250.00	
		3 861.73
Accounts Receivable		
Membership dues	9 554.50	
Initiation fees	540.00	
Sale of publications, advertising, etc	6 360.04	
		16 454.54
Advances account of land subscription fund		9 955.22
Advanced payments		1829.65
Total Assets		$637 352.38

LIABILITIES

United Engineering Society (for cost of land)		$81 000.00
Funds		
Life Membership Fund	$35 151.07	
Library Development Fund	4 902.71	
Weeks Legacy Fund	1 957.00	
Land Fund Subscriptions	223.88	
Subscriptions to Annual Meeting	46.93	
		42 281.59
Current Accounts Payable		2 652.33
Membership dues paid in advance	804.25	
Initiation fees paid in advance	75.00	
		879.25
Initiation fees uncollected		540.00
Appropriation available to complete Vol. 31 of Transactions		4 200.00
Reserve (Initiation fees)		27 926.97
Surplus in property and accounts receivable		477 872.24
Total Liabilities		$637 352.38

EXHIBIT B

Income and Expenses for the Year Ended September 30, 1910

INCOME

Membership dues		$ 57 551.79	
Sales gross receipts		9 210.25	
Advertising receipts		24 230.26	
Interest and Discount		1 684.01	
			$92 676.31

EXPENSES

Finance Committee Office Administration including Salaries	$20 205.68		
Finance, United Engineering Society Assessments	4 500.00		
Finance, Miscellaneous	634.36		
		$25 340.04	
Membership Committee		2 350.49	
Increase of Membership Committee		2.70	
§House Committee			1 089.16
Library Committee			2 491.46
Meetings Committee			
Annual Meeting	2 394.40		
Spring Meeting	2 028.72		
Monthly Meetings	3 416.92		
London Meeting	2 270.23		
		$10 110.27	
Publication Committee			
Advertising Section The Journal	11 791.32		
Journal, except Advertising	18 527.88		
Year Book	2 748.73		
Revises	131.96		
Transactions Volume 31	2 801.79		
		$36 001.68	
		$77 385.80	
Research Committee		100.76	
Thurston Memorial Committee		139.06	
Sales Expenditures		4 401.28	
Total			$82 026.90
*Excess of Income over Expenses			10 649.41
			$92 676.31

§From Current Income $1,089.16
Reserve Fund 3,000.00

Total Expenses $4,089.16

*Of this amount $4,200.00 is reserved to complete Volume 31 of Transactions.

EXHIBIT C

Receipts and Disbursements for Year Ended September 30, 1910

RECEIPTS

Membership dues	$49 888.25	
Initiation fees	6 345.00	
Membership dues and initiation fees paid in advance	948.00	
Sales of publications, badges, advertising, etc	31 733.56	
Subscriptions to Land Fund	616.00	
Subscriptions to Expense of Annual Meeting	360.20	
Interest	2 168.23	
	$92 059.24	
Cash in Banks and on hand, September 30, 1909	20 613.22	
		$112 672.46

DISBURSEMENTS

Disbursements for general purpose	94 214.14	
Interest on Mortgage on Land	3 240.00	
	97 454.14	
Cash in Banks and on hand, September 30, 1910	15 218.32	
		$112 672.46

LAND FUND

RECEIPTS

Subscription	$71 662.76	
Interest	573.56	
Advances from Society	9 955.22	
Property, 12 W. 31st St	63 000.00	
	$145 191.54	

DISBURSEMENTS

Acquisition of property	7 971.11	
Mortgage	99 000.00	
Interest	27 766.92	
Furnishings and equipment	7 671.81	
Occupancy building, moving library	2 171.06	
Expenses of Committee	386.76	
Cash on hand	223.88	
		$223.88
	145 191.54	

Cash on hand	223.88	
To be raised	90 731.34	
	90 955.22	
Amount of mortgage	81 000.00	
Advances by Society	9 955.22	
	90 955.22	

LIFE MEMBERSHIP FUND

Number of Life Members	90	
Number of Life Associates	6	
Number of Life Juniors	1	
	97	
97 Members at $15 = $1455		
4 per cent interest on $35,151.07 and credited to unappropriated revenue	$1 406.04	
Amount Oct. 1, 1910	35 151.07	35 151.07

LIBRARY DEVELOPMENT FUND

Amount Oct. 1, 1909	4 902.71	
Balance Oct. 9, 1910		4 902.71

WEEKS LEGACY

Amount Oct. 1, 1909	1 957.00	
Balance Oct. 1, 1910		1 957.00

THURSTON MEMORIAL FUND

Subscriptions	788.32	
Interest	36.47	
Current Income 1909–1910	139.06	
	963.85	
Expenditures		
Bronze Memorial	850.00	
Reflector bracket	30.00	
Booklet	32.04	
Committee expenses	51.85	
	963.85	

ANNUAL MEETING SUBSCRIPTION

Balance in the hands of the Local Committee and held by the Society in trust		46.93
		$42 281.59

The Committee also submits herewith as called for by the By-Laws a detailed estimate of the probable income and expenditure of the Society for the ensuing fiscal year:

ESTIMATE OF INCOME 1910-11

Dues	$57,525
Sales, gross receipts	5,000
Interest and discount	475
Advertising	25,500
	$88,500

ESTIMATE OF EXPENSES 1910–11

	FROM CURRENT INCOME	FROM RESERVE
Finance Committee	$28,740	
Membership Committee	2,450	
Increase Membership Committee	500	
House Committee	600	$ 400
Library Committee	4,500	
Meetings Committee	9,000	
Publication Committee	36,400	*1500
Research Committee	300	
Public Relations Committee	100	
Committee on Power Tests	300	
Sales Expenditure	3,000	
Reserve Fund	600	
	$86,490	$1900

Respectfully submitted,

ARTHUR M. WAITT, *Chairman*
R. M. DIXON
E. F. SCHNUCK
W. M. MARSHALL
G. W. ROBERTS
} *Finance Committee*

REPORT OF THE HOUSE COMMITTEE

Your Committee during the year has completed the work embodied in the decorative scheme outlined in its last report. This included the tinting of the walls and the furnishing of new carpets, new

*Advanced on account meeting in England to be paid out of current income.

draperies and new furniture in the entrance hall, Council room and library. It is felt that these rooms now present an attractive, quiet and dignified appearance appropriate to the home of the Society.

Your Committee also acquired a uniform series of photographs of all the Past-Presidents, which are now hung upon the walls of the library.

Your Committee has in mind the extension of its original program with a view to unifying the plan of decoration in such of the rooms as are open to the general public, and hopes to carry out these plans during the coming year.

Your committee further proposes to secure photographs of the Honorary Members, to be framed in conformity with the photographs of the Past-Presidents already hung upon the walls.

Respectfully submitted,

WILLIAM C. DICKERMAN, *Chairman*
BERNARD V. SWENSON
FRANCIS BLOSSOM
EDWARD VAN WINKLE
H. R. COBLEIGH
} *House Committee*

REPORT OF THE LIBRARY COMMITTEE

No radical changes have been effected in the library organization during the past administration year.

The libraries of the three founder societies are being operated in parallel, the actual library work being handled jointly by the library staff and the administration of the libraries being conducted under an informal Library Conference Committee consisting of the chairman of the library committees of the founder societies.

It is expected that more intimate relationships between the libraries will be established in the near future.

It is also expected that the United Engineering Societies' library will be organized and that gifts of libraries and books may be received by it where they are not made a specific donation to the library of one of the founder societies.

The number of visitors accommodated at the library shows a continued increase as indicated by the following tabulations:

	Day	Night	Total
July	609	Closed	609
August	560	Closed	560
September	596	261	857
	1765	261	2026
Night	261		
Total	2026		

	1908		1909		1910	
	Day	Night	Day	Night	Day	Night
January	541	148	485	250	460	286
February	439	241	533	254	416	232
March	417	203	535	280	439	256
April	403	210	529	217	488	274
May	400	196	462	221	454	279
June	419	136	484	198	471	239
July	441	closed	472	closed	609	closed
August	362	closed	472	closed	560	closed
September	393	125	434	220	596	261
October	381	180	471	238		
November	435	200	479	223		
December	520	441	545	301		
	5151	2080	5901	2402	4493	1827

Membership cards received

American Institution Electrical Engineers	10
American Society Mechanical Engineers	8
American Institution Mechanical Engineers	20
Non-members	8
	46

As an indication of the range of subjects called for by visitors to the library and the relative frequency of consultation, the following table may be of interest, covering the months of April-September 1910.

	April	May	June	July	Aug.	Sept.
Architecture	1	2	1		1	1
Bibliography						2
Biography	1				1	1
Chemical Technology	4	5	4	2	3	1
Chemistry	4	4	2	1	2	2
Civil Engineering	7	1	5	2	2	5
Description and Travel	1	1	1	1		
Electrical Engineering	17	12	22	6	20	14

	April	May	June	July	Aug.	Sept.
Electricity	2	9	1	5	5	1
Engineering (General)	5	6	14	5	10	10
Geology	22	9	10	7	24	20
Hydraulic Engineering	2	3	4	2		10
Mathematics	5		1	1		9
Marine Engineering						
Mechanical Engineering	27	23	26	13	16	19
Metallurgy	14	4	11	13	4	1
Mining Engineering	16	11	20	9	9	6
Miscellaneous	1		3	4	1	4
Periodicals	49	28	89	30	39	90
Physics	7	2	2	3		7
Railroad Engineering		5		1		5
Railroad Engineering (Electrical)	1					7
	196	125	216	105	137	215

It has been felt that the appropriation available for the purchase of new books is inadequate to keep the library supplied with the latest books of reference.

The amount expended for books and periodicals in 1908 was $527.76. An approximately similar amount will be expended during the current year and your Committee in presenting its request for the appropriations for next year has submitted a request that the appropriation under this head be increased to $1500.

Your Committee has in preparation a book plate for the Society's library which will be submitted for the approval of Council of the Society at an early date.

Respectfully submitted,

J. W. Lieb, Jr., *Chairman*
Ambrose Swasey
Leonard Waldo
Chas. L. Clarke
Alfred Noble

Library Committee

REPORT OF THE COMMITTEE ON MEETINGS

In addition to the Annual and Spring Meetings of the Society, 18 additional meetings have been held. Of this number six were held in each of the cities of New York, Boston and St. Louis. During 1910 and 1911 meetings will also be held in San Francisco. At a number of these meetings sister societies and local engineering organizations coöperated, but the number of meetings given does not include those of other societies in which we coöperated.

It is the policy of your committee to meet weekly, excepting during the summer months, and including special meetings the Committee has practically carried out this policy during the period mentioned.

Fifty-four papers and three topical discussions have been accepted and published in The Journal, all of which have been or will come before meetings of the Society. These include eight papers presented at the meetings held at Birmingham and London.

Several cities other than New York, Boston, St. Louis and San Francisco are contemplating holding meetings, but they have not as yet reached a definite conclusion.

It has been suggested that appropriations be assigned for meetings, based on the number of members accessible to a locality. For the present, however, your Committee believes that the Society should do all possible to assist the membership in different localities in which these meetings are being held, to the limit of the available funds.

Your Committee finds that the local conditions vary at the different points and therefore repeats the suggestion contained in its report to the Executive Committee of May 31, 1910, that after more extensive experience of all the local committees on meetings has been obtained, they, in coöperation with the Committee on Meetings, formulate such rules as may be found necessary to establish uniformity in the conduct of all local meetings, the same to be subject to the approval of the Council.

A meeting of the local members at New York was held October 31, 1910, for the recommendation of names for a local committee, that New York City may be organized on the same basis as all other localities. It is intended that this committee, by the selection of some 20 assistants, shall also act as the entertainment committee for the Annual Meeting.

Your Committee has felt for some time that the papers presented before the Society have not been sufficiently diversified. It believes that it has overcome this to some extent, but with the further object of making the Transactions of the Society a more complete record of mechanical engineering progress, a circular has been mailed to the membership calling their attention to this point, which it is believed will result in materially increasing the value of the Transactions of the Society as a record of engineering progress. The attention given the circular so far is most gratifying and the membership is to be congratulated upon the interest it has inspired.

The rapid growth of industrial establishments has developed a

phase of mechanical engineering—that of economic administration—which your Committee feels should be given the attention by the Society that its importance warrants. This branch of the profession has evolved the administrative engineer until a very large percentage of the profession and of our membership is now occupying administrative positions in industrial establishments. Your Committee has had this question under attention for some time, but until recently it did not feel that the opportune time for definite action had arrived.

At its meeting, October 7, 1910, it requested the endorsement by the Council of the appointment of a sub-committee on the Economic Administration of Industrial Establishments. The committee is glad to have the Council's approval of its request and believes the field covered by this sub-committee can be made one of the greatest factors in our economic welfare.

Permit the Committee again to call the Council's attention to the recommendation that it feels the best interests of the Society would be subserved by a closer working arrangement between the Research Committee and the Committee on Meetings.

The Committee begs to thank the officers of the Society and the members of the office staff for the coöperation and assistance it has received.

Respectfully submitted,

WILLIS E. HALL, *Chairman*
WM. H. BRYAN
L. R. POMEROY
CHAS. E. LUCKE
H. DEB. PARSONS

Meetings Committee

REPORT OF THE MEMBERSHIP COMMITTEE

During the current year the Membership Committee has held six meetings, at which the total of 337 applications for membership have been considered with the following results:

Withdrawn for various causes	14
Deferred indefinitely	17
Recommended for membership	306

Of the 306 names recommended for ballot 276 were candidates for new membership and 30 were candidates for promotion. The candidates recommended were voted for on two ballots submitted to the membership as follows:

Spring ballot..... 159
Fall ballot..... 147

The small number of names deferred and the fact that no objections have been received to the names placed upon the professional service sheets testifies to the increasing care taken by the members in filling out the application blanks, and to the careful manner in which all cases are studied in the Secretary's office before being submitted to the committee. The Committee, however, would emphasize again that its work will be greatly facilitated and the standards of the Society safeguarded if members will agree to act as proposers and seconders of an applicant only when they can support the latter through personal knowledge of his work.

The Committee desires to report that the new rules regarding the Junior and the Associate membership grades put into effect at the spring meeting, have operated upon the whole in a very satisfactory manner, and in the judgment of the committee have placed the classes of membership upon a basis that makes for the best interests of the Society.

The Committee would recommend that it be given authority to prepare a list of approved engineering schools that will be used to interpret the phrase "engineering schools" in clause C-11 of the Constitution relating to the admission of Junior members.

Respectfully submitted,

C. R. Richards, *Chairman*
George J. Foran
Theodore Stebbins
Francis H. Stillman
Hosea Webster
Membership Committee

REPORT OF PUBLICATION COMMITTEE

The Committee has had to meet the constantly growing number and length of papers presented to the Society by the members of its annual, monthly and local meetings by a very careful elimination or condensation of everything which might be termed extraneous or superfluous in order to keep within the confines of a single volume of the Transactions.

Volume 31, just issued for 1909, contains 1069 pages and the current Volume 32 embracing, in addition to the Society papers, the papers presented at the English meeting will contain between 1500 and 2000 pages. This would be considered the outside limit of size.

The largest volume heretofore printed was No. 24 for 1903 which contained 1563 pages and was thought unwieldy, and yet if the growth of our available matter continues at anything like its present rate, we will be confronted with the necessity of binding Transactions in volumes of about this size. An alternative would be the omission of the printing of the Transactions altogether as such, thereby avoiding the duplication of 75 per cent of the reading matter of The Journal.

This would be done by printing in The Journal previous to meetings a list only of the papers which will be read at the meeting, requesting members who desire to discuss any particular paper to send for a copy of it. After the meeting, The Journal would publish all papers with all discussions and at the end of the year would supply binders in which all copies of The Journal may be bound. This volume would continue the present series of Transactions. By this means the papers would be printed once only instead of twice and the annual saving to the Society would be approximately $5000, which could be applied to making the Library more accessible to members.

Previous to this year, The Journal has been published monthly, except in July and August when there were no issues, and in October and November to accommodate the additional amount of matter necessitated by the Annual Meeting it has appeared semi-monthly. This year however, the arrangement has been changed so as to have it appear monthly throughout the year.

The gross and net cost of issuing the Society publications is given in the following tables for each of the past five fiscal years ending September 30.

EXPENDITURES

	1906–1907	1907–1908	1908–1909	1909–1910	1910–1911
History		$ 95.06	43.65		
Revised papers		182.56	523.93	131.96	300
Year Book and Pocket List	2 232.35	2622.57	3000.89	2748.73	3200
Transactions	8 400.20	6100.00	6533.87	7001.79*	8600
The Journal	11 487.98	8425.58	20160.86	30319.20	25800
	22 120.53	17425.77	30263.20	40201.68†	37900

INCOME

Advertising			11997.50	24227.26	25500
Appropriations	22 120.53	17425.77	18265.70	15974.42	12400

* Approximate.
† Estimated.

It will be seen that the net cost to the Society is gradually being lessened; the slight increase for 1908–1909 being due to the change in the issue of both the Year Book and the Pocket List to a combination of the two in one.

There has never been a complete cross-reference index of the Transaction, and there has been for a long time a crying need for one. Recently the Library Committee has had in mind the indexing of the Transactions of all the Societies and it will be necessary to carry out a complete indexing of our Transactions in this connection. The Committee is now in conference with the Library Committee on the best method of coöperation in this work.

Respectfully submitted,

D. S. JACOBUS, *Chairman*
H. F. J. PORTER
FRED R. LOW
GEO. I. ROCKWOOD
GEO. M. BASFORD
Publication Committee

REPORT OF THE RESEARCH COMMITTEE

The last formal meeting of the Research Committee was held December 10, 1909. At that meeting it was agreed that it would be unwise for the Committee to enter at once upon the investigation of problems of research. It was agreed that as a preliminary to actual work there should be on file in the office of the Secretary, a complete list of the college, commercial and other laboratories of the country, the organization of which might permit them to do work in line with the purposes of our Society. In addition to the name and the location of the laboratory, it was proposed to have the name and address of its director and a statement concerning the extent of its staff and equipment, also a list of the subjects which have been investigated and a reference as to where the reports thereof may be fo nd, a statement of the problems now under investigation, and a statement of the field of engineering for which the laboratories are especially equipped. The circulars which have been sent out have been worded so as to make it clear that the Committee does not wish to intrude itself upon the activities of any laboratory, but that the inquiry grows out of a desire on the part of the representatives of a national organization to know how thoroughly the field is now covered. The responsibility for sending out these circulars and for tabulating the information obtained was left with the Secretary of the Society.

It is the understanding of your Committee that the work of gathering this information is now practically complete, and that there is on record in the Secretary's office all information along this line.

It was also agreed that the Committee might properly undertake a research concerning the performance of safety valves, and a circular has been issued designed to develop the most important facts which should be determined concerning the action of such valves. These were sent to 68 safety valve manufacturers, to 125 railroads of 100 miles or over, and to three large boiler manufacturers. Forty-one replies have been received. Eighteen have no information regarding Pop Safety Valves. Nine of the replies are of especial interest and have been abstracted as follows:

The Consolidated Safety Valve Company refers to Mr. Philip Darling's paper before the Society in 1909 and to experiments of Professor Miller of the Massachusetts Institute of Technology. They favor a high lift for steam passage. As to the rating of the various sizes they favor the continuation and duplication of the Darling and Miller tests. Nickel bronze is favored for valve seats and copper bronze with 10 per cent tin for valves. To maintain efficiency they favor keeping the exhaust steam away from the spring, and exposure to air currents for cooling. They consider the aperture has little effect on the capacity but is an important element of the lift. They suggest experiments to develop the effect of temperature and of steady loads and rapidly varying loads, on springs, also a study of the various rules governing sizes and design of various supervising authorities with the aim to develop a safe and uniform rule, applicable to all sizes. They suggest that many common faults of safety valves be made the subject of reports in boiler inspection service. Railroads which have a system of report covering engine failures might also outline the most common troubles with safety valves.

The Ashton Valve Company refers to the tests of Professor Miller, of the Massachusetts Institute of Technology. They favor the low lift from a practical standpoint with 30 years experience. They suggest tests determining a proper rating of safety-valve boiler based on the capacity of relief that the valve should give. They favor high grade composition of bronze metal made of copper and tin about 8 to 1. Regarding efficiency they make outside spring valve with spring free from steam exposure for use where steam temperature is over 400 deg. fahr. As to aperture bevel seat valves 45 deg. angle give best results. Regarding additional facts they express the opinion that it will be difficult to establish a rule adaptable to both stationary and locomotive boilers and they discuss this point at length.

Crane Company know of no reliable data regarding discharge but refer to A. J. Hewling's discussion, in The Journal, June 1909. They are willing to submit valves and take part in public tests in order that reliable data may be had. They favor high grade composition of valve and valve seats and state that they have no experience of springs losing temper. Facts about the effect of the shape of the apertures have led them to adapt a cushion disc and spring which allows the highest lift practicable. As to tests they

suggest that the committee provide accommodations where safety valves may be tested under the same conditions and under most careful observation.

The Lunkenheimer Company do not know of any accurate data other than manufacturers tests. They favor a lift of $\frac{1}{16}$ in. to $\frac{5}{64}$ in. They suggest time tests to determine the efficiency and lift of valves with various lifts under a wide range of actual service conditions and pressures. They favor nickel bronze composition, high percentage of nickel for the seat and a high grade steam metal for the disc. The outside spring type of valve is used to avoid undue heat and to maintain the efficiency. As to the shape of the aperture, they suggest six points to be considered. For research they suggest the evolution of a simple and practical rule for determining sizes based on a moderate constant lift.

Crosby Steam Gage and Valve Company have submitted a reply of some thirty pages accompanied by illustrations and catalogues. For data they refer to the Annual Report of the U. S. Steamboat Inspectors, 1877, thesis of Bardsley and Miller, Case School of Applied Science, 1906, data of tests referred to in Steam Boilers by Professor Peabody, p. 240, and tests now being made at Massachusetts Institute of Technology, 1910. Regarding the lift in safety valves they cite the experience of manufacturers' measurements at factories and in actual service, measurements made at the Massachusetts Institute of Technology, 1909. They suggest fixing standard or limits of lift, to insure durability to valves; measuring discharge of various designs of valves at same fixed lifts, reporting minimum lift and discharge which have been in past ample, and refining characteristics of operation most desirable in safety valves. They favor bronze composition, high percentage of tin, low in zinc and lead. Nickel composition not to be endorsed. Exposing springs outside of valve body involves friction; encasing spring in inner chamber involves sticking; long spindles, large valve casings, well drained spring chambers essential without sliding contacts. Regarding open shape of aperture, see tests of Massachusetts Institute of Technology in Steam Boilers by Professor Peabody; also tests in progress at Massachusetts Institute of Technology; also Kent's Pocketbook, p. 724. For research they suggest verbal explanation in detail of essential characteristics of design of each valve as made; of the general principles involved, and defense of engineering reasons, advantages and objections governing each detail; in other words, the engineering "confession of faith" of each manufacturer and his own exegesis of each article of it.

Rock Island Lines: W. A. Nettleton knows of no boiler being blown up because the safety valve fails to properly relieve. Statistics of Mr. Curtis of the Master Mechanics Association Committee indicate very few boilers explode from over pressure, the majority explode from low water, due generally to carelessness. This applies to locomotive service in which the boiler is very closely watched. As to the durability, a number of small valves are preferable to a very large one. He is skeptical regarding the tendency towards a higher lift. He has had no experience as to temper of the spring and steam. He assumes spring losses of elasticity because of repeated strains.

Canadian Pacific Railway Company: Mr. Vaughan, Vice-President, considers it desirable to investigate for flat seats and V-shaped seats. The amount of steam flowing per hour with different heights of lift, the height to which valves now in use lift with given increments of pressure, the effect of various forms of coupling devices based on the pressure between the seat of the valve

and the muffler, so as to attain data on which to base a specification providing that a given diameter should have a lift of not less than a certain amount to the given increment of pressure between the seat, that there should be not more than a certain amount of pressure between seat and muffler device, that the area through the muffling device should have a certain proportion to the area of the valve.

Stirling Boiler Company: Mr. Fred Scheffler refers to the formula on p. 9, 1910 catalogue of consolidated safety valve, with 45 degrees beveled seat and actual evaporation tests. Also states that complete data can be obtained from Consolidated Safety Valve Company and the Naval Experimental Station, Annapolis, Md. He favors composition seats with twenty-five per cent metal. Regarding deterioration, he states that a well-designed spring should not lose temper under saturated steam, and that an exposed spring should be used under superheated steam. Very complete information has been published by the Consolidated Safety Valve Company in their book entitled Safety Valve Capacity.

Heine Safety Boiler Company: Col. E. D. Meier writes that experimental data are mainly in the possession of various firms and companies which manufacture high class valves, and cites the Consolidated Company, the Ashcroft Company and the Ashton Company, who have recently installed a boiler suitable for 400 lb. pressure for continuing such experiments. He states that the rules promulgated by various officials and societies seem to be based on experiments made at lower pressure than current practice. These rules may be deficient because action of metals under higher stresses and higher temperature will be different than in the early experiments. Mr. Geo. H. Musgrave has had some experience as a pioneer and is an enthusiast on the subject. There is great need of experimental work and the only safe way for a scientific settlement of these questions would be tests on entirely neutral grounds, i.e., in the laboratory of some well equipped mechanical engineering school of high repute. His company has to conform to three different rules: the regulations of the Board of Supervising Inspectors of Steam Vessels; the Philadelphia Boiler Law; the Boiler Rules of Massachusetts. They give different dimensions so designers are guided by the locality where the boiler is to be operated. An important question is the limit in size, that is, when it becomes necessary to put two or even three safety valves on a boiler in place of one. The amount of lift has a bearing on this.

It may be deduced from the above correspondence that what is needed in determining a method of rating valves is not so much research as it is standardization of practice, defined by recommendations having the weight of the Society behind them. For example, the testimony seems to show that valves having low lift and high lift are operative, and that advocates of both are to be found among people well qualified to pass opinions on the operation of valves in service. It may be that lift is a factor which, while hitherto regarded as of importance, may be neglected, and that its effect will be entirely absorbed in any arrangement which will secure a rating of valves in

accordance with their discharge capacity. This and other general questions which have been developed by its inquiry will be considered at a formal meeting of the Committee to be held at the time of the next annual meeting of the Society, at which time it should be possible to take the next step in the development of the Committee's work.

Respectfully submitted,

W. F. M. Goss, *Chairman*
R. C. Carpenter
R. H. Rice
Ralph D. Mershon
Jas. Christie

Research Committee

MODERN SHOE MANUFACTURE

By M. B. Kaven, Beverly, Mass.

Member of the Society

J. B. Hadaway[1], Beverly, Mass.

Non-Member

Some of the earliest forms of foot-wear of which we have any definite knowledge had soles made of various materials, such as wood, fibre and leather, fastened to the feet by thongs or straps. Other forms consisted of mere blocks of wood with holes in which to incase the feet.

2 A somewhat improved form of foot-wear was made by nailing leather uppers to wooden soles and such shoes were often shod with iron to protect them from wear.

3 A greater amount of ingenuity and skill was shown in making shoes from pieces of leather, cut to predetermined shapes and sizes, which were sewed together by hand. This latter method probably led to the invention of the shoe last, which is a wooden block conforming to the desired shape of the shoe, and over which the uppers are molded or lasted during the process of manufacture.

4 The most perfect shoe devised by artisans of this ancient craft, previous to the introduction of shoe machinery, is undoubtedly that known to a few of this generation and to many of the past generation as a hand-sewed shoe.

5 The method of making this shoe consists in first cutting and then sewing together the different parts of the upper; next, shaping the insole to the required form and cutting in its under surface near the edge a shoulder and channel to form a rib to which the upper is sewed. The insole (see Fig. 1) is then secured to the bottom of the

[1] United Shoe Machinery Company.

The American Society of Mechanical Engineers, 29 West 39th Street, New York. All papers are subject to revision.

last, the upper being drawn over the last and edge of the insole and temporarily secured to the insole with lasting tacks. With a sharp curved awl the workman makes a hole at the breast of the heel-seat through the rib of the insole and upper and the edge of a narrow strip of flexible leather called a welt, which is sewed to the outside of the upper along the edge of the last to which the outsole is later secured (see Fig. 2).

6 One end of a waxed thread about 5 ft. in length is inserted in the hole made with the awl and drawn through a distance equal to one-half the length of the thread. Another hole is then made through the materials at a distance of about $\frac{3}{8}$ in. in advance of the first hole,

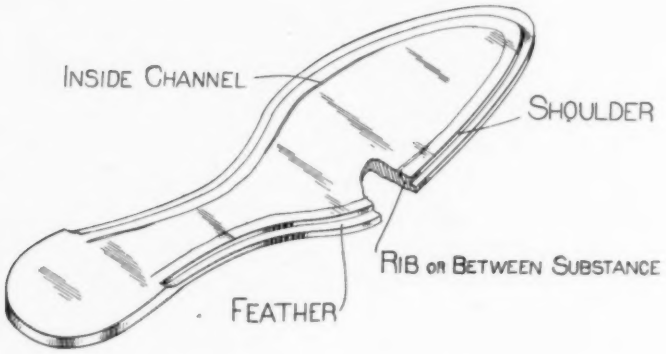


FIG. 1 INSOLE FOR HAND SEWED SHOE

and the two ends of the thread are inserted in this second hole from opposite sides and drawn through tight, thereby uniting the welt, upper and insole at that point, and forming the first stitch of the inseam. These operations are repeated until the seam has been sewed completely around the forepart of the shoe, terminating at the breast of the heel upon the opposite side. The lasting tacks are withdrawn, the surplus leather below the inseam trimmed off, and the welt beat out flat.

7 The outsole is then cut to the required size and temporarily secured to the bottom of the last, after which it is sewed to the welt, the seam being placed a short distance in from the edge and following the contour of the sole. The stitches of this seam are made much shorter than those of the inseam and for that reason the operation is necessarily slow and requires great skill.

8 The heel is built upon the heel seat of the shoe by nailing to it

layers of leather until the proper height has been obtained after which it is trimmed to the required shape.

9 As the principal operations in the process of making a hand-sewed shoe have been described, the subsequent finishing operations will not be explained.

10 Fifty years ago the size of the average shoe shop would not have measured more than 12 by 15 ft., nor would the average number of men employed in each shop have exceeded three persons. Each workman was taught the whole trade and was often required to select

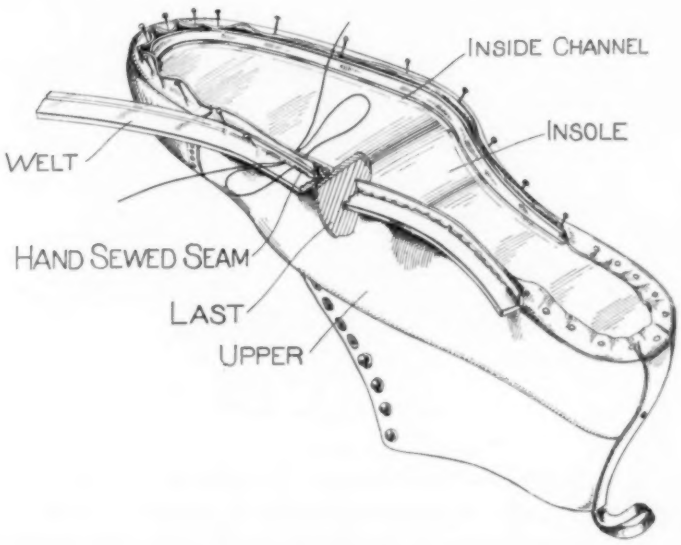


FIG. 2 HAND SEWED SHOE

and cut his own stock and make a complete shoe. The tools employed were all hand implements, even the grindstone used to sharpen the cutting tools being turned by hand.

11 About this period men with inventive minds began to devise means for performing with machinery many of the operations in the making of shoes which were being done by hand, and their efforts were attended with marked success. The most important machine developed during that period was undoubtedly the McKay sewing machine, which united the outsole to the insole by a chain-stitch seam passing through these two soles and leaving a portion of the seam exposed upon the inside of the shoe (Fig. 3). It was therefore necessary

to insert in the shoe a secondary insole or sock-lining to prevent the seam from hurting the feet.

12 Other machines built for fastening soles to shoes perhaps required as great mechanical ability to perfect but were of less importance commercially. Among them was the pegging machine which automatically cut pegs from a strip of wood and drove them through the outsole into the insole, thereby fastening the sole. The ends of the pegs projected through the insole and made it necessary to cut them off before the shoes could be worn.

13 The screw machine was also used to some extent. It screwed

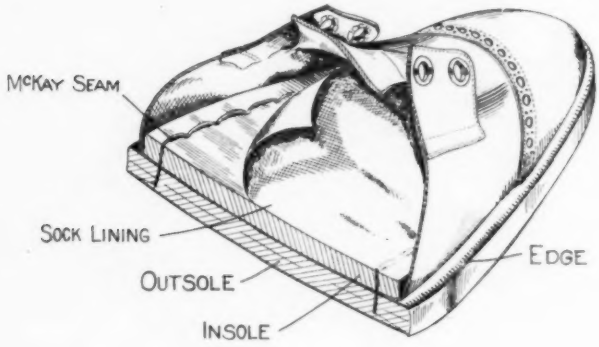


Fig. 3 McKay Shoe

a portion of a threaded wire through the outsole into the insole and then severed the wire at the tread surface of the sole, thus automatically cutting the wire screw the exact length of the thickness of the substance it penetrated.

14 The loose-nailing machine drove nails by a hammer blow through the outsole and insole and clinched them upon the inside of the shoe by driving the ends against an anvil set in the end of a horn shaped to enter the shoe.

15 In order to use these different machines it was necessary first to last the shoe, tack on the outsole and then withdraw the last in order to permit the horn to be inserted during the sole-fastening operation. The greatest defect in shoes made by the aid of these machines was that the different fastening materials penetrated the tread surface of the insoles and often roughened them to such an extent as to cause discomfort to the wearer.

16 Machines were invented for performing many operations pre-

viously done by hand but the paramount object was to produce machinery for making shoes by the hand-sewed method, since such shoes when finished contain insoles which are perfectly smooth upon the inside of the shoe, and since they are more flexible than those made on the machines previously mentioned.

17 Inventors spent much time and money in attempting to perfect machinery for making shoes by this method, a result finally achieved through the efforts of Mr. Charles Goodyear. About twenty years ago the Goodyear Shoe Machinery Company placed upon the market a practical inseam sewing machine an and outsole

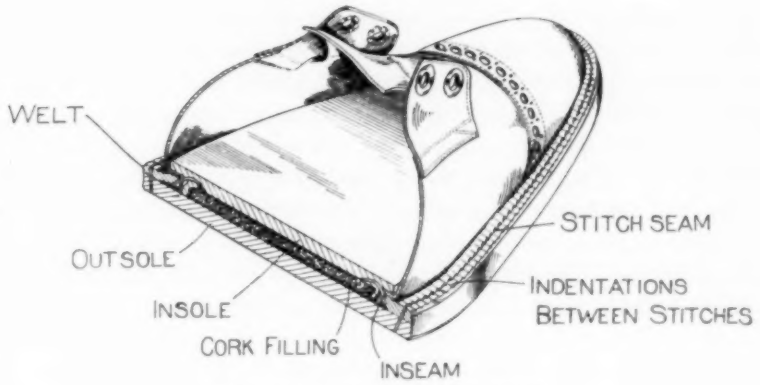


FIG. 4 GOODYEAR WELT SHOE

stitcher. Since that time these two machines have been greatly improved upon and hundreds of them are now in daily use in many parts of the world.

18 The introduction of machinery for making Goodyear welt shoes (Fig. 4) revolutionized the industry. The small shops have been superseded by large shoe factories in which thousands of pairs of shoes are made each working day. Where formerly one man made the complete shoe, it is now worked upon by more than 100 different operatives, and more than 60 different machines are used in the process.

THE MODERN SHOE FACTORY

19 As the Goodyear welt shoe represents the highest type of footwear in appearance, comfort and wear that has as yet been produced,

a description will be given of a modern shoe factory, the methods employed and the machinery used in the process of making them.

20 A modern shoe factory is, as a rule, a well-made, four-story building, well-lighted, and equipped with the latest sanitary arrangements for protecting as far as possible the health of the workmen. The power plant is installed in a one-story building outside the main building midway its length.

21 Steam is generally used to generate power and furnish heat electricity for lighting purposes; and the automatic sprinkler system to protect the building and contents from fire. The factory is also equipped with the automatic fire alarm, and with elevators, suitable stairways and fire escapes.

22 An exhaust fan system is used to extract the dust and dirt from the different departments in which abrasive and trimming machines are used. This dirt is conveyed to a receptacle near the power house from which it is taken and burned under the boilers.

23 The first floor is divided into a sole-leather stock room and a sole-leather cutting room; the general offices, the finishing room, treeing and dressing room, and the packing and shipping room are located upon the second floor; and the entire third floor is used as a making room. The fourth floor is divided into the upper-leather stock room, the upper-leather cutting room and the stitching room.

MACHINES AND OPERATIONS

24 When orders are received at the factory, they are recorded in an order book and given a number, and each lot made under that order is designated by a case number. Tags bearing order numbers, together with the details affecting the preparation of the stock, are sent to the cutting and sole leather rooms. Work sheets are daily sent to all of the different departments designating the work required of each for that day.

25 The first operations in the making of shoes, which consist of cutting the upper leather and linings into the required shapes and sizes, are performed in the cutting room. Formerly all such operations were done by hand by workmen who laid patterns upon the leather and then drew a sharp knife along their edges, thereby cutting the leather to conform to them; but to-day this work is done upon a clicking machine, provided with a cutting board very similar to those used by the hand workmen. Extending above the cutting board is

a beam which can be swung over any portion of the board and which is secured to a vertical shaft connected at one end by an eccentric strap surrounding an eccentric upon the driving shaft of the machine. The eccentric shaft is driven by a single revolution clutch to impart to the beam a predetermined downward and upward movement.

26 The skin to be cut is laid upon the board and the operator places a die upon it. Grasping a handle, which is connected to the beam, he causes the latter to swing over the die and by a downward pressure of the handle causes the clutch to operate so as to bring the beam downward and press the die through the leather. As soon as this is accomplished the beam returns to its full height and is automatically swung sideways from over the die.

27 The dies used are but $\frac{3}{4}$ in. in height and of very light weight. The tops of these dies are left open and the opening is substantially the same size and contour as the pieces of leather cut with them, thus enabling the operator to see clearly the entire surface of the leather he is cutting out. It is obvious that pieces of leather cut with any given die must be identically the same in shape. After the different parts required for each lot have been cut, they are tied in separate bundles and the lot number marked upon the top piece in each.

28 The edges of the parts which show on the finished shoe, such as vamps, tips, quarters, etc., must be skived with either a shoulder or beveled edge upon the flesh side. This work is generally performed by a skiving machine, by which the edge of the piece of leather to be skived is fed by feed rolls and held by peculiarly shaped guides against the edge of a sharp revolving disc which cuts the edge to the desired bevel, irrespective of the curves and angles in the edge of the piece of leather operated upon.

29 The pieces which have been skived are fed through a machine which deposits an even coating of cement upon the skived surfaces. After the cement has dried to the proper degree the skived edges are folded upon a folding machine, which turns back the edge about $\frac{3}{16}$ in. and folds it down upon the balance of the skived portion.

30 It will be observed that when the edges of leather having a grain surface have been skived, cemented and folded in the manner described, they will present a very even, smooth and finished appearance. It may be well to add that the folding machine is provided with a knife for cutting slits in that portion of the edge which is folded over in order to make such leather lie down smoothly when folding curved edges.

31 The ornamental perforations cut along the edge of the toe

cap are generally made by a power press, fitted with a die containing a multiplicity of punches for cutting all the perforations simultaneously. It is necessary to use a stripper plate with such dies in order to withdraw the punches from the leather. The punches, which are hollow, cut against a paper band supported by the bed of the machine. A portion of the band is fed after each perforation, in order that a new surface may come under the die for the next cutting. This method insures perfect work.

32 Another form of perforating machine is one used for long and irregular curved pieces. It is provided with a spindle which carries one or more small tools to perforate the work and feed it a predetermined distance. These operations are repeated until the work has been perforated the required distance.

33 On one of the top linings of each shoe is stamped the case number, width and size, by a special stamping machine made for the purpose.

34 After all parts of the upper have been prepared in accordance with the instructions on the tag for this department, and assembled, they are forwarded to the stitching room. Here the different parts of the upper are united.

35 The stitchers, the majority of whom are women, are divided into different classes, and while the lining stitchers are making the various styles of linings, others are at work stitching tips to vamps, ornamenting tops with fancy stitching, closing backs of vamps and tops and back-staying the same, working button holes on the buttonhole machine, and performing other operations according to the style of shoe manufactured. When the tops and vamps have been made ready, they are stitched together on a cylinder vamping machine, an operation requiring skill and accuracy as the success of the future making of the shoe depends greatly upon the work of the vamper. In the stitching room are performed many other minor operations, such as cementing, rubbing seams, strap making, etc., all of which require deftness and dexterity.

36 In this room is also used the duplex eyeletting machine, which eyelets both sides of the shoe at one time with bewildering rapidity.

37 The next and last operation performed in this department is the lacing of the upper upon the lacing machine, which passes strong twine through the eyelets, lacing five pairs and tying the two ends of the twine together at a single revolution. This is done so that all parts of the shoe upper will be held in their normal position while the shoe is being made.

38 With the completion of this operation the preparation of the shoe upper is finished and the different lots with their tags sent to the making or bottoming room; there to meet the different sole leather portions, which in the meantime have been prepared in the sole leather room in accordance with the instructions written upon the tags.

39 The outsoles are cut from sides of leather on large dieing-out machines, which press heavy dies through the leather, or are roughly cut from strips of leather on a block sole cutting machine. The heavy firm portions of the hide which will bear the greatest amount of wear are used for outsoles and top lifts of heels, while the coarser and more flexible portions are used for insoles, taps, counters, toe boxes, welting and heel lifts. These outsoles are fed through a rolling machine where they are subjected to many tons of pressure between heavy rolls, to solidify the leather and increase the wear; and are then fed through a splitting machine which reduces them to an absolutely even thickness. The shank portions are reduced on a skiving machine in order to give the edges a better appearance in the finished shoe.

40 The insoles are trimmed to an exact size on a rounding machine in which the roughly died-out pieces of leather are held between clamps, one of which is the exact pattern of the sole. The pattern and sole are held in a stationary position, while the knife which trims the sole is secured to a yielding carrier completely encircling the sole, and the cutting edge of the knife follows the contour of the pattern. They are then fed through the channeling machine, provided with two knives, one of which cuts a slit along the edge of the insole, and the other a channel in the flesh surface a short distance in from the edge. A lip turning machine is used to turn the lips over against the flesh surface of the insole to form a shoulder, against which the upper is lasted, and to which the upper and welt are later sewed.

41 The toe boxes and counters are cut with dies to the required sizes and skived on a special skiving machine which reduces their edges to a knife-edge thickness. The object of so shaping them is to prevent their edges from forming lines which otherwise would show in the finished shoe.

42 The heels to be used upon these shoes are formed of different lifts of leather cemented and nailed together in a heel-building machine, and placed in layers in a press, subjected to sufficient pressure to hold them flat until the cement sets or hardens. The top lifts, which are later attached to the heel, are compressed in a special machine under many tons of pressure to solidify them, thus greatly increasing their wearing qualities.

43 The first work in the bottoming room is the selection of the lasts required for each lot of shoes, after which the insoles are automatically tacked to the bottoms of the lasts by means of the insole tacking machine. It is necessary to bevel slightly the edges of the heel-seats of the insoles after tacking, to conform to the curves of the last. This operation is preformed by a recently invented machine, provided with a rotary cutter and novel guiding means.

44 The toe box or stiffening is now pasted between the toe tip and the lining of the upper and the counter placed between the heel portion and lining. The last is placed inside the upper and put upon the spindle of the assembling machine, which drives a tack in the back of it to bring the heel portion of the upper and counter into position, and folds a portion of the counter and upper over the edge of the last and insole, securing them by an additional tack.

45 The upper in this condition upon the last is passed to the operator of the pulling-over machine. This is one of the most important machines in the process of making shoes, for the parts of the shoe upper have been cut to conform exactly to the shape of the last, on which they must be correctly placed to secure the desired results. The pincers of the machine grasp the leather at different points on each side of the toe; and the operator, standing where he can see when the upper is exactly centered, presses a foot lever causing the pincers to close and draw the leather securely against the wood of the last. At this point the operator stops the machine and by moving different hand levers which control the pincers he is able to adjust accurately each part of the shoe upper to the position intended for it. The foot lever again being pressed, the pincers move towards each other, drawing the leather securely over the last and at the same time automatically driving three tacks on each side and one at the toe, which hold the uppers securely in position.

46 The assembled parts attached to the last are now ready for the lasting process, which is one of the most difficult operations to perform properly, and for which two types of machines are used.

47 The bed type of machine is usually employed to last the toe and heel portions, while the type known as the "hand-method" welt-lasting machine is used to last the sides, although in some instances it is used to last the whole shoe. The former type is provided with a series of wipers which draw the leather from all directions over the edge of the insole about the toe and heel portions in a very smooth and efficient manner. Before releasing these wipers, the leather is secured in position upon the last by a piece of fine wire passed about

the toe and secured at each end by tacks, the crimples of the surplus leather preventing it from slipping. The surplus leather crimpled in at the heel is forced smoothly down against the insole and held there by tacks driven by a hand tacking machine, in which there is a constantly renewed supply.

48 The hand-method machine which is used for lasting the sides takes its name from the almost human way in which it performs its work. It draws the leather with pincers, evenly and tightly about the last, and, while held in position, tacks are automatically driven into the last a portion of their length to hold the edge of the upper exactly in place. After the shoe has been lasted it is necessary to keep it in that state for a few hours so that the leather may retain the shape to which it has been stretched.

49 There is also left a surplus amount of leather and lining at the toe and along the sides of the shoe projecting over the edge of the insole which must be removed. This is done by the use of the upper-trimming machine, provided with both a rotary and an oscillating knife which cut very smoothly and evenly.

50 On the heel portion of the shoe, the tacks are driven through the insole and clinched on the iron heel of the last, but elsewhere they are driven only part way in, so that they may afterward be withdrawn and leave the inside of the shoe perfectly smooth. They are removed by the tack pulling and resetting machine, which is provided with a pair of jaws which grasp the tack beneath the head, withdraw it, and then throw it into a tube leading to a receptacle at the back of the machine. This device is also provided with a mechanism for driving special soft wire tacks automatically through the upper and into the rib of the insole, temporarily holding the upper in place during the sewing operation.

51 A narrow groove is cut in the welt a short distance from its edge to receive the thread of the inseam, and the insoles are moistened preparatory to being sewed on the Goodyear welt sewing machine (Fig 6), from which these shoes derive their name. The operation of this machine, as previously stated, consists of sewing the welt and upper to the insole.

52 After the shoe has been sewed, the surplus leather above the inseam is trimmed off by the inseam trimming machine, to permit the outsole to lie flat against the seam. The knife which does this trimming is saucer shaped and runs at a high rate of speed.

53 The ends of the welt are skived to a knife edge, after which it is beaten out on the welt beater, in which a hammer vibrates

very rapidly under a yielding pressure. The welt so treated stands out flat from the edge of the shoe. As it is bent about the toe during the sewing operation, it has a natural tendency to draw more tightly at that place, and this strain is relieved by a knife in the beating machine which cuts diagonal slits in the edge of the welt at that point and is under the control of the operator. The tacks which fasten the insole to the last are now removed by the insole tack-pulling machine, and the bottoms of the shoes are filled with a preparation made of ground cork and rubber cement, which prevents the penetration of moisture in damp weather.

54 A steel shank is tacked to the shank portion of the shoe to support the arch of the foot and to help keep the shoe in shape.

55 The bottom of the shoe and of the welt now receive a coating of rubber cement. This cement is contained in an air-tight tank, so that there is very little waste through evaporation, which when applied by hand is excessive. It is applied by means of a revolving brush, which takes its supply of cement as required and in this way gives an even coating of any desired thickness.

56 The flesh surface of the outsole also receives a coat of rubber cement and is allowed to dry to the required degree, after which it is stuck to the bottom of the prepared shoe by the twin sole-laying machine, which is provided with a rubber pad or mold which has been made to conform to the curves in the sole of the shoe. After placing the shoe on the spindle suspended from the upper part of the machine directly over the rubber mold, the sole with its cemented surface is pressed against the bottom of the shoe, and the operator by pressing a foot lever causes the shoe to descend into the mold. By pressing a second lever, additional pressure is brought to bear, forcing every portion of the sole against the bottom of the shoe and welt. Here it is allowed to remain for a sufficient length of time for the cement to set properly. Meanwhile the sole of another shoe is laid in a similar manner in the duplicate or twin portion of the machine.

57 The next operation is that of trimming the edge of the sole and welt to the shape required. This work is performed on the rough rounding and channeling machine. As it is often desired to have the edge extend further on the outside of the shoe than it does on the inside, and generally to have the shank portion trimmed somewhat closer than the forepart edges, this machine is provided with automatic means for performing such operations. Simultaneously with the rounding operation the machine cuts a channel along the edge of the sole (Fig. 5).

58 After the completion of this operation, the shoe is taken to the loose nailing machine, which drives small nails automatically through the heel-seat of the outsole and insole, clinching them against the iron plate upon the heel of the last, thus securely fastening that portion of the sole. The latest improved type of this machine is capable of driving 1400 nails per min., but the average operator is incapable of operating the machine at much more than one-half its capacity upon many kinds of work.

59 The surplus portion of the sole about the heel-seat is trimmed

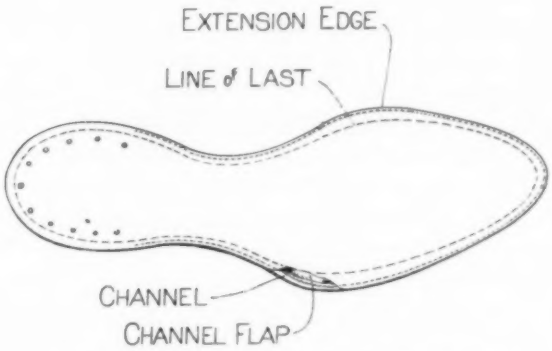


FIG. 5 OUTSOLE OF GOODYEAR WELT SHOE
ILLUSTRATING THE RELATIVE CONTOUR OF LAST AND OUTSOLE

off on the heel seat-rounding machine. The lip of the channel cut by the rough rounding and channeling machine is turned up by the channel-opening machine, which has a peculiarly shaped revolving tool for the purpose.

60 The outsole is now sewed to the welt by the outsole rapid lockstitch machine. The stitched seam extends from the root of the channel cut in the outsole through to the surface of the welt, where the stitches show after the shoe has been finished. This machine, which is fitted with a curved awl and needle to sew with hot waxed thread, is capable of sewing very closely to the upper of the shoe, irrespective of the many curves in the last. It contains a rotary shuttle to carry the bobbin which forms the lockstitch, and is provided with a takeup thread-measuring device, and other suitable thread-handling instrumentalities. The lockstitch seam which it forms is very durable and holds the outsole securely, even after the connecting stitches have worn off.

61 The channel lip of the outsole is now forced into its former position to cover the stitches. By the channel flap-laying machine, in which a rapidly revolving wheel provided with a peculiar arrangement of flanged projections forces the leather smoothly and evenly back into place.

62 The shoe is now ready for the sole leveling operation, which is performed in the automatic sole-leveling machine, so nearly automatic in every particular that all the operator is required to do, apart from the making of adjustments for different styles of shoes, is to jack and unjack them. The machine is provided with two jacks, on one of which the operator places the shoe to be leveled, after which it is passed automatically beneath a vibrating roll under heavy yielding pressure. This roll is controlled by a cam-actuated mechanism which causes the roll to tip so as to level the sole to the required form. At the completion of the leveling operation the jack which supports the shoe is returned to its first position ready for the shoe to be taken from the machine, a shoe having meanwhile been secured upon the second jack and forced forward into the machine to be leveled.

63 The heel of the shoe is now nailed in place by the heeling machine, which performs its work very rapidly and perfectly. The shoe is placed in position on a jack and the heel nails, which have been set in the holes of a plate, are swung into position exactly over the heel and automatically dropped into a die containing holes corresponding to the places where the nails are to be driven. On pressing a foot lever all the nails are driven at one time through the heel, the upper and the insole and are clinched upon the inside of the shoe. The heads are left slightly protruding above the heel so as to retain the toplift which is now placed in position. The operator again presses the foot lever and the machine presses the toplift down over the heads of the nails. This operation is called blind nailing.

64 The shoe is next taken to the slugging machine, which drives short pieces of wire, called "slugs," in and about the edge of the toplift to protect it from wear. This machine will automatically drive and cut from a continuous coil of wire as many as 1000 slugs per minute.

65 The heel is trimmed by the heel-trimming machine, in which a set of very rapidly revolving knives cut away all the rough and surplus portions of leather, leaving the edge of the heel quite smooth and the exact contour intended. Since the toplift is the exact size

of the bottom of the heel, it is used as a guide by the operator when trimming, as is also the edge of the heel-seat of the shoe.

66 The breast of the heel, or that portion which extends over the sole at the shank, is trimmed on the heel-breasting machine. The cut may be made straight across or concave, and with the required slant. The shoe is placed upon the jack of the machine and the tread surface of the heel forced against a plate to support the heel during the descent of the knife, which cuts smoothly through each lift of leather to the exact point at which the heel is joined to the outsole, but without cutting into it. The curve of the knife exactly conforms to the rounded form of the shank portion of the sole.

67 The edges of the heel are now scoured on the heel-scouring machine to make them perfectly smooth and even. This machine has two rolls on which molded sandpaper is fastened, conforming exactly to the contour of the heel. These rolls are driven at a rapid rate of speed, the leather dust scoured from the heels being taken away by the exhaust-fan system previously mentioned.

68 It now becomes necessary to rand or trim away, at a slight bevel, a portion of the surface of the welt outside the line of stitching which fastens the sole to the shoe, in order that subsequent operations in the making of the edge may be properly performed. The beveled portion of the welt is rubbed down hard and smooth to make it retain its shape. These two operations are performed on the trimming and rubbing machine, in the head of which are two shafts which revolve at a high rate of speed. Upon one is mounted a thin beveled cutter, protected at its periphery by a guard to prevent its cutting the stitches of the seam. The second shaft is fitted with a serrated rubbing wheel for rubbing the surface of the welt.

69 Water is now applied by means of a brush to moisten the welt preparatory to separating the stitches, in which operation indentations are made in the leather, crosswise of the welt, in the intervals between the stitches, for the purpose of giving to the surface of the welt an ornamental finish. This work is performed on the stitch-separating machine, and is provided with a feed slide upon which is mounted, by connected mechanism, a tool post to hold the stitch-separating tool. The feed slide has imparted to it a predetermined positive-feeding movement, adjusted to correspond to the longest stitch in the seam to be separated. The tool, however, feeds the work each time a distance equal to the exact length of the stitch separated, whether it be of uniform or of varying length.

70 This result is accomplished by bringing the point of the sep-

arating tool against the surface of the seam with a yielding pressure, and then vibrating the tool lengthwise of the seam to cause its point to enter the interval between the stitches. Further vibrating movement, after the tool has been located in the interval between the stitches, will not move the extreme point of the tool, but instead, the tool holder, to which the tool is fastened and which is held in its normal position by friction, will be rocked about the stud upon which it is mounted. After the completion of the locating movement the tool is forced into the welt a pre-determined distance, with a positive pressure, to separate the stitches and make the required indentation in the welt. This being accomplished, the work is fed the length of the stitch separated. A correcting mechanism moves the tool to its normal position after each feeding movement; otherwise, the machine would fail to accurately locate the intervals between the stitches. It is intended to make the stitches in the seam of equal lengths, but because of the inequalities in the leather and the slight differences in the pressure exerted by the operator while making the seam, the stitches often vary considerably in length, although such variations are hardly perceptible to the eye of the average person.

71 If the machine be set to separate the stitches of a seam containing on an average of 10 stitches to the inch, some individual stitches may be found to average 8 and others 12 to the inch, yet the machine will accurately locate each interval between such stitches, or any length of stitches between the two extremes mentioned. In some instances it is preferred that the stitches be drawn into the welt slightly below its surface. This is termed a fudge stitch, in making which an impression wheel is used to produce a series of indentations on the surface of the welt very similar to those made by the stitch-separating machine.

72 The indentations are afterwards burnished on the burnishing machine. This contains an impression wheel which is free to revolve as the work is fed beneath it, but is positively vibrated lengthwise of the indentations at a high rate of speed to polish them.

73 The edge of the sole is now evenly and smoothly trimmed to the desired shape on the edge-trimming machine, provided with a rapidly revolving cutter for trimming the edge of the fore-part of the shoe, and another slightly different in shape for trimming the edges of the shank portion.

74 After the edges and welt of the shoe have received a coating of special blacking and become sufficiently dry, they are set and burnished on the edge-setting machine. In this, two hot irons, shaped to

fit the trimmed edges, vibrate very rapidly, and the edge of the shoe held against them is quickly set or hardened and given a brilliant and lasting polish.

75 The surface of the top-lift is now made perfectly flat and even on the toplift-sanding machine, the operator holding the surface against the sanded face of a large revolving disc.

76 The breast of the heel is scoured on a small machine fitted with a rapidly revolving cone-shaped disc, surfaced with sandpaper, which brings this portion of the shoe to a proper finish.

77 The edge of the heel is given a coating of special ink on the heel-blacking machine, which contains a reservoir of ink and automatically feeds the amount required to the surface of two brushes revolved in opposite directions. By holding the heel against the brushes the edge is thoroughly and evenly coated with ink, and is finished on the heel-finishing machine.

78 This machine is provided with an iron wheel of peculiar construction made up of a number of segments lying diagonally across its surface and conforming to the varying shapes of heels. Hot wax is automatically conveyed to the surface of the iron wheel, which is also heated. The edge of the heel being held against the wheel, the ink and wax are thoroughly rubbed into the leather, and the heel is then presented to a revolving pad on the machine, which polishes the edge, receiving a final finish by being held against a rapidly revolving brush to give it the required brilliancy.

79 The bottom of the shoe is buffed on the buffing machine, on which two rapidly revolving rolls, covered with sandpaper, remove the outside surface of the grain of the leather for the purpose of adding to the appearance of the bottom when finished. As the shank portions of the sole cannot be properly buffed with these rolls, the buffing machine is used for this purpose. This is an entirely different type of machine. It contains a vertical shaft, upon the lower end of which is mounted a pad of rubber covered with emery cloth revolved many thousand revolutions per minute. An air pump with which the machine is fitted keeps the rubber pad constantly inflated with air, not only keeping the emery cloth cool but adding flexibility to the pad so that it conforms to the surface of the leather being buffed.

80 The bottom and top-lift of the heel are blacked or stained and brought to a highly polished surface on the finishing machine, which has a revolving shaft fitted with different brushes made of cloth or bristles as may be required for the particular kind of work to be performed.

81 Another form of finishing machine known as the stitch and upper cleaner is fitted with special brushes and used for the purpose of polishing the stitches and leather about the indentations in the surface of the welt. It is also used to brush off any dirt which may have accumulated upon the upper of the shoe up to this point in its manufacture.

82 In order that the quality of the shoe may be recognized, a trademark or trade name is generally stamped on the bottom of the sole or in the shank. This work is done by a power stamping machine whereby the operator is enabled to press the heated die against the bottom of the sole under any desired pressure, regulated by hydraulic means.

83 The last, over which the upper was drawn early in the making process, has been allowed to remain in place through all the various operations so that the finished shoe may acquire and retain exactly the shape desired. It is at this point that the last is withdrawn and the shoe placed over the form of the treeing machine. This is the shape of the last, but is collapsible. The pressure of a foot lever in this machine expands the form inside the shoe until it fills it entirely and the operator, using various tools, rubs out every wrinkle that may have made an appearance in the shoe upper and cleans or dresses it with such preparations as will give to the shoe the best appearance. The releasing of the foot lever causes the expanded form to collapse, and the shoe is removed without disturbing in any way its form or finish.

84 The shoe is then inspected and the upper receives its final coat of dressing. Now being finished, it is packed in a carton and made ready for shipment to the purchaser.

WELT-SEWING MACHINE

85 The welt-sewing machine (Fig. 6) is by no means the most complicated in the system of machines for making Goodyear welt shoes, but since it is the most important one, its construction and mode of operation will be briefly described.

86 The head of the machine is mounted upon a post which can be adjusted in a suitable base so as to permit the machine to be set to the height most convenient for operation. The principal parts of the thread-handling mechanism are a curved open-eyed sewing needle, looper, thread finger, takeup, auxiliary-takeup, tension wheel and tension-wheel governing device.

87 The machine has a circular awl for feeding, and a channel guide, both of which are secured to levers mounted upon the feed slide of the machine. It is also provided with a suitable device for holding and guiding the welt, and a back rest to assist in supporting the shoe during the sewing operation. All of these different parts are given their respective movements by levers actuated by a series of cams fastened to the driving shaft of the machine.

88 A steam-heated wax pot attached to the machine holds hot wax to be applied to the sewing thread.

89 The stitch made by this machine is known as a chain-stitch, but is not made by the ordinary method, in which a number of the parts of the machine mentioned could be dispensed with.

90 To sew, it is necessary first to turn the driving shaft to a position that will permit the shoe to be placed in the machine, the end of a strip of leather welting being inserted in the welt guide. The operator takes the shoe by both hands and places it in the machine, pressing it against the point of the awl and of the channel guide at the bottom of the inside channel of the insole at the breast of the heel-seat. By pressing a foot lever, the machine is set in motion, and under the guidance of the operator the welt is sewed to the shoe along the side, around the toe to the breast of the heel-seat upon the opposite side of the shoe, thereby uniting the welt, upper, and insole by a strong, durable, wax-thread seam.

91 To describe a stitch made by this machine, we will presume that a few stitches have already been made in a seam and that there is a loop of thread in the eye of the needle which has been drawn through the work through the previous loop, and which is longer than the required length of a stitch, and that the needle is in its extreme position away from the work with the loop taut in the eye of the needle. Starting the machine at this point, further movement will cause the awl to descend and be forced into the between-substance or rib at the bottom of the inside channel of the insole, when the awl feeds the shoe the length of a stitch to a position which will bring the awl and needle in line. The needle will then descend and be forced through the edge of the welt, upper and between-substance of the insole, going through the hole made in the between-substance by the awl, which during this movement has been withdrawn from the work and out of the path of the needle. During the forward travel of the needle, the loop of thread in the eye will have been forced down upon the shank of the needle by contact with the work. The takeup lever next acts to draw the previous stitch tight,

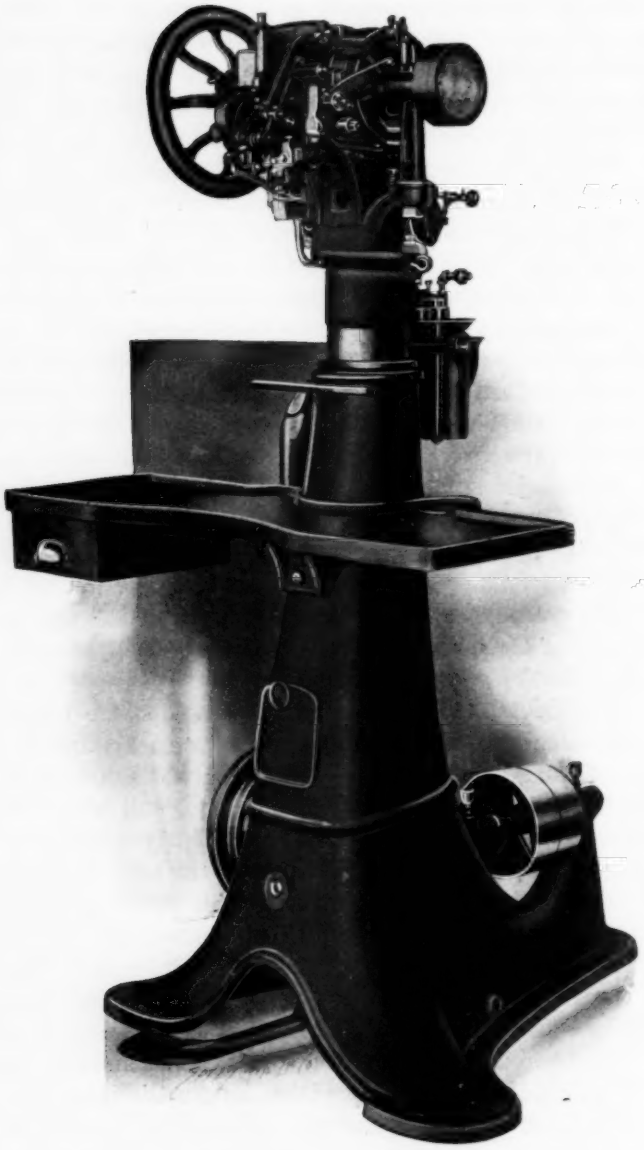


FIG. 6 WELT SEWING MACHINE

taking up the slack thread and pulling the loop tight about the shank of the needle with a strain equal to that exerted by the tension device upon the thread; the continued movement of the takeup drawing an amount of thread from the wax pot or thread supply equal to the amount of thread used in forming the previous stitch. The thread finger now moves to measure off a predetermined amount of the thread taken from the thread supply by the action of the takeup.

92 The looper is next moved in a path about the point of the needle and places the thread in the eye of the needle, the thread being kept taut during such movement by the action of the auxiliary takeup. The needle then acts to pull the new loop of thread through the work, through the previous loop, and to set one leg of the new loop taut against the between-substance of the insole at the root of the channel.

93 The movement of the thread finger should have displaced just enough slack thread to cause the needle to bite the thread at a point in its length which will pull one leg of the loop taut against the between-substance of the insole; shorten the previous loop an amount due to the difference between the area of a cross section of the shank of the needle and the area of two cross sections of the thread of which the loop is made; and pull the new loop taut in the eye of the needle with only a slight reaving movement of the thread through it. A revolution of the camshaft of the machine has now been completed, bringing it to its first position, a stitch having thus been formed in the work by the thread-handling mechanism.

94 The welt is guided about the shoe by the guide locked against the shoe during the time the needle is pulling the thread through the work, and helps to support the work against the pull of the needle. It is again locked against the shoe when the awl is puncturing the insole; and is also given an automatic pullback movement, regulated to a predetermined throw, to allow the shoe to feed clear of the guide and to help draw the welt through it in such a manner as to lay the proper amount of welt around the shoe. It is moved back during the formation of each stitch a uniform distance from the point of contact with the shoe, regardless of the varying thicknesses of the between-subtance to be sewed, so that it is locked at varying distances away from the point of the channel guide.

95 The back rest is locked against the shoe to help support it during the action of the needle and again during the thrust of the awl which punctures the insole.

96 An operator can sew on this machine in a day as many shoes as 100 hand-workmen previously sewed in the same length of time;

and since the sewing thread has been treated with hot wax and pulled by t'.e machine with unvarying tension, the seams are stronger and wear better than those made by hand.

97 The results obtained by the use of the different machines which we have described enables shoe manufacturers at the present time to produce Goodyear welt shoes to retail at prices ranging from $3.50 to $7 per pair, which for comfort, style, and superior workmanship, excel those made by custom workmen to sell at prices ranging from $12 to $18 per pair.

OPERATING CONDITIONS OF PASSENGER ELEVATORS

By Reginald P. Bolton, New York
Member of the Society

This paper is concerned with the principles that affect and limit the service of passenger elevators, which constitute the most important adjunct to the improvement of real estate and which are continually being more widely used in this connection.

2 The operation of a passenger elevator is unlike that of other reciprocating mechanisms, in that its movements are designedly dependent upon the entrance and exit and the weight of the persons making use of its car. The time during which it is in actual motion is therefore only part of the total time of its service, and it will be manifest that some due proportion of the total time may be expected to be occupied by passenger movement and by machine motion respectively, and should either one or the other be of undue proportion, the result will be a reduction in efficiency, as represented by traffic.

3 Passenger time is that which is consumed while the car is not in motion, but is awaiting the movement of passengers. In schedule service, which is the method of operation universally adopted in business buildings, the period of actual waiting time at the lower floor is limited by the schedule, but in addition to this time, the movement of passengers in entering and leaving the car and the processes of opening and closing the gates occupy a further proportion of the total time of use of the elevator.

4 The period of inaction of an elevator thus has a close relation to the number of passengers carried, and in schedule service the average consumption of time which the writer advanced in a recent work on this subject has been found by experiment to prevail in various cities, indicating that personal characteristics in the use of elevators are very similar in all parts of the country. These allowances are:

The American Society of Mechanical Engineers, 29 West 39th Street, New York. All papers are subject to revision.

a For each person carried either way ..... 5 sec.
b For each person entering at the lower landing ..... $1\frac{1}{4}$ sec.
c For each person leaving at lower landing ..... $\frac{3}{4}$ sec.
d For the process of making and leaving the upper landing ..... 9 sec.

The waiting time at the ground floor, in addition to the foregoing is extended to suit the schedule, which is fixed by the division of the round-trip time between the number of elevators in use. In several tests of the traffic of schedule service, by making the foregoing deductions from the total time occupied, the actual running speed of the elevator car has been correctly predetermined and in others, by deducting the known running time from the total, the foregoing allowances have been substantiated.

5 The machine time is occupied by three main elements:
a Acceleration from a state of rest to designed speed.
b Travel at designed speed.
c Retardation from designed speed to a state of rest.

The average speed of the machine is not its designed or nominal

TABLE 1 MEAN SPEED AT VARIOUS FUNCTIONAL DISTANCES

Flight	Functional Distance	
	10 Ft.	15 Ft.
Ft.	Ft. Per Sec.	Ft. Per Sec.
12	4.60	3.73
15	5.00	4.16
18	5.35	4.52
24	5.90	5.13
30	6.33	5.55

speed, but that which results from the mean time occupied in the foregoing operations. The designed speed may not be attained unless the flight or distance between stops is such that the processes of acceleration and retardation from and to a state of rest do not occupy the entire space of time and distance.

6 Fig. 1 shows the course of these functions on a horizontal scale of time and a vertical scale of space, with the mean speeds resulting therefrom. Line AB is that of the designed speed of the car at 500 ft. per min. Curve CD is that of the function of starting and stopping on the up-run within distances respectively of 6 and 4 ft. and $C'D'$ the same operation on the down-run and within a flight from landing to landing of 15 ft. The mean speed is reduced to 5 ft. per

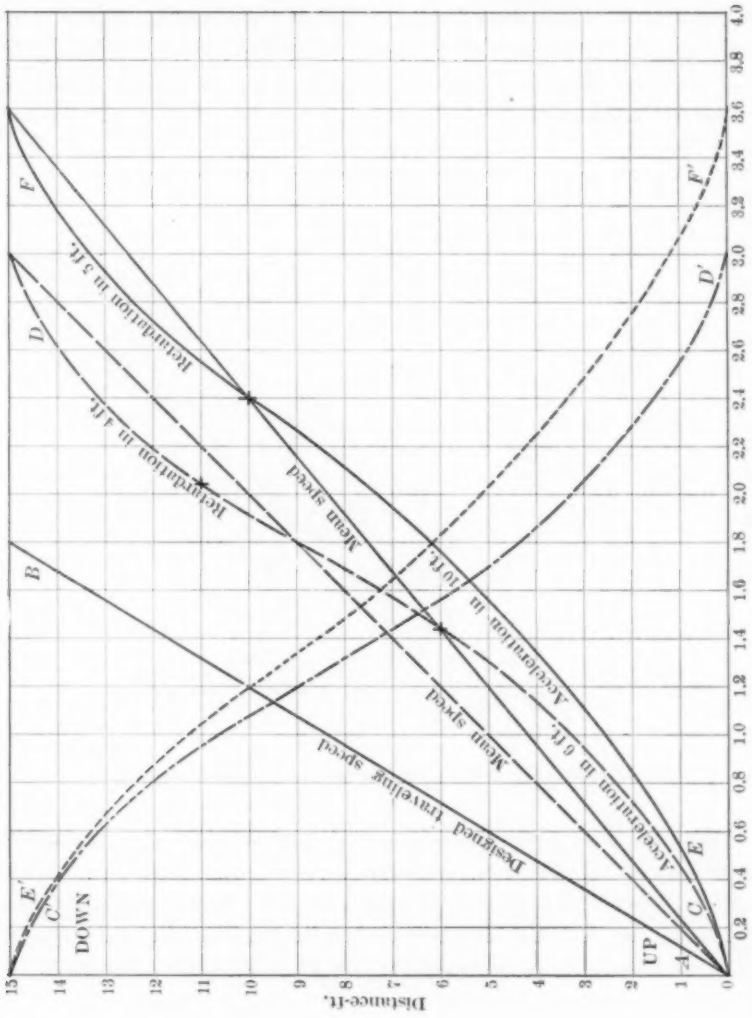


FIG. 1 SPEEDS AT VARIOUS FUNCTIONAL DISTANCES

sec., a drop of 40 per cent from the designed speed. Curves EF and $E'F'$ are those of the same functions exercised in a distance of 10 ft. and 5 ft. respectively, thus occupying the entire space from landing to landing and reducing the mean speed to 4.16 ft. per sec., or 50 per cent of the designed speed. From these and similar curves the mean speeds given in Table 1 have been deduced. In curve EF it will be seen that the car on attaining its designed speed, is immediately slackened by the commencement of the process of

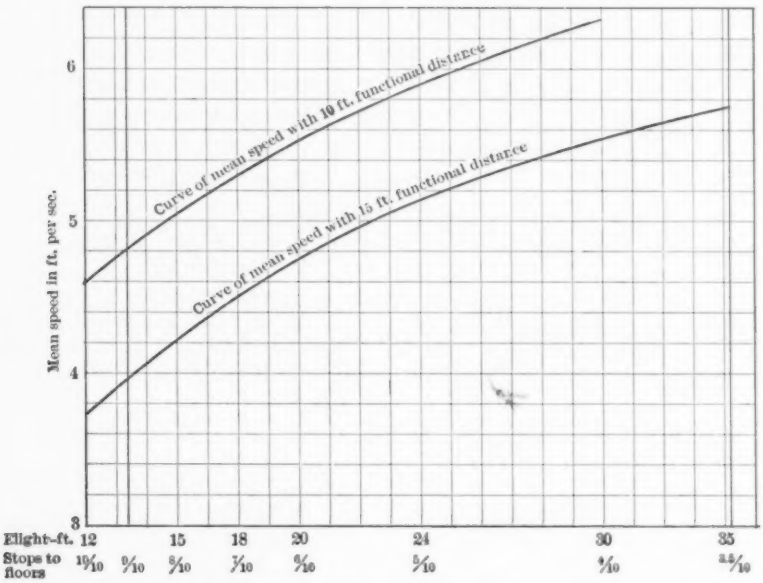

Mean speed in ft. per sec.
6
5
4
3
Curve of mean speed with 10 ft. functional distance
Curve of mean speed with 15 ft. functional distance
Flight-ft. 12 15 18 20 24 30 35
Stops to floors 19/10 9/10 8/10 7/10 6/10 5/10 4/10 3.5/10

FIG. 2 MEAN SPEEDS BETWEEN LANDINGS AND CORRESPONDING SERVICE

retardation so that the designed speed is not utilized at any less distance than 15 ft. between landings.

7 Fig. 2 shows these rates of speed at the same two functional distances plotted for all distances between landings from 12 ft. to 35 ft., with the corresponding character of the service expressed in percentage of landings to floors.

8 The gain by the shorter functional distance when making any service is about 12 per cent of machine time, and such an elevator will, if sufficiently powerful for the increased load, attain the same mean speed with $\frac{6}{10}$ traffic as is attained in the other machine with four landings in ten floors.

9 The live load in the car and the weight of the car itself directly affect the functions of acceleration and retardation, aiding or opposing each operation inversely on the up and down runs. Where there is no counterweight or balance applied to the live load, these effects are directly proportioned to the latter. In hydraulic elevators it is not usually practicable to counterbalance the live load, but it is the universal practice to counterbalance some part of the live load

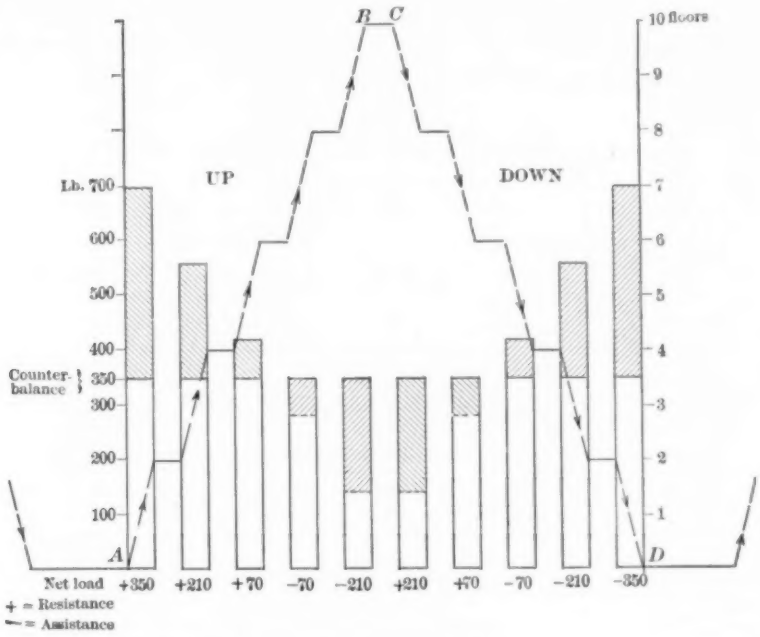


FIG. 3 EFFECT OF COUNTER BALANCE

in electric elevators, relieving to that extent the two operations in either direction. As electrically operated elevators are now largely in the majority and are constantly on the increase, the relation of the counterbalance to the average live load carried each way appears to be a most important feature and it would be desirable to ascertain it in some definite manner rather than by theoretical assumption.

10 Elevator loads are varied on the up and down runs in the manner shown in Fig. 3, in which the flights and stops of a car are shown by line *ABCD* and the weights by the shaded parallelograms. The overbalance, if it be one-half of the commencing and ending live loads, has the theoretical effect of bringing about a complete balance of

lifting and lowering work, and theoretically the net overbalance lifted on the one side is used as descending force on the other. It is due to this feature that the electrical form of elevator will give back a certain amount of motor-generated current to its supply line. The amount so returned is but a portion of that used in lifting the overbalance and is usefully employed only if there be some means of absorbing or utilizing the current. The motor must also be back-rotated to that speed necessary to produce a voltage equal to that of the circuit which is only the case when it has attained its designed speed, so that this economic feature is also dependent on the average distance between stops and starts.

TABLE 2 TESTS AT NIGHT AND DAY BANK BUILDING

AVERAGE LOADS—CAR NO. 2

Hour	Persons Each Way, Average	LIVE LOAD, LB.		
		100-200	200-300	300-400
7- 8	0.75	105	—	—
8- 9	2.09	—	292	—
9-10	2.62	—	—	366
10-11	2.33	—	—	326
11-N	1.91	—	267	—
N-1	2.55	—	—	338
1-2	2.67	—	—	349
2-3	2.65	—	—	347
3-4	1.29	181	—	—
4-5	1.73	—	242	—
5-6	1.67	—	233	—
6-7	0.94	131	—	—
Averages		139	259	345

11 The effect of overbalance is also varied by the fluctuations of the live load in either direction during the hours of traffic, and should this traffic be uneven or such as to vary considerably from the designed relation of load to overbalance, then the benefit of the overbalance is disturbed and its value is considerably impaired.

12 The relation of traffic to counterbalance is therefore a matter of importance, and economy may be effected by ascertaining what proportion the average loads each way bear to the overbalance. These relations may be ascertained after the appliance is in full operation by counting the passengers, but this observation is not of value unless the counting is made of every individual carried each way during some given period of time.

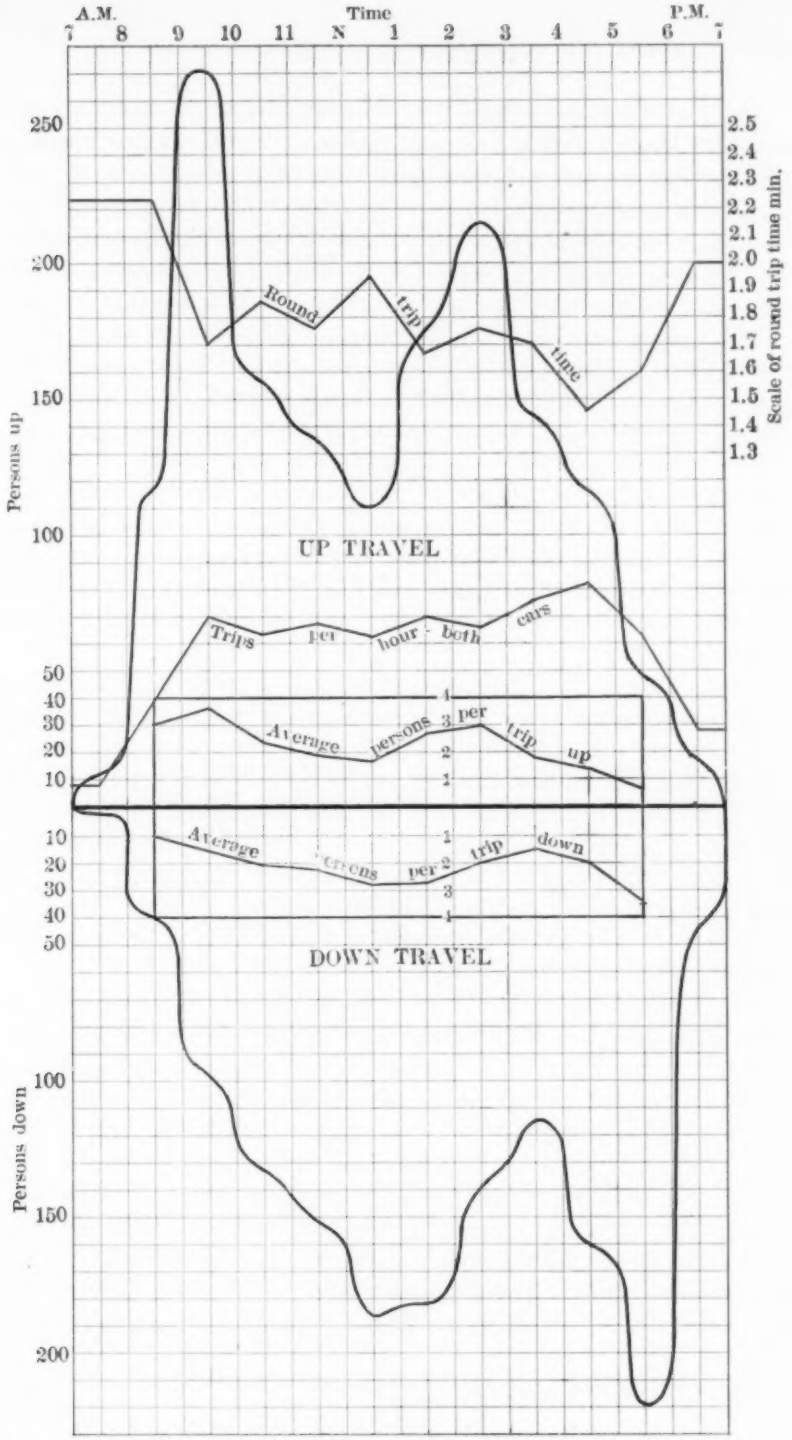


FIG. 4 ELEVATOR TRAVEL IN NIGHT AND DAY BANK BUILDING. NEW YORK CITY

13 The observed operation of the traffic in the cars of the Night and Day Bank Building is shown in Fig. 4, in which are plotted on the vertical scale above and below the middle horizontal line the number of persons carried up and the number of persons carried down on each hour of the business day. This observation shows that the distribution of traffic in such a business and professional building closely coincides with the theoretical distribution advanced by the writer.[1] In the traffic of this building, the heaviest periods of elevator work are from 9 a.m. to 10 a.m. for one-way traffic, and from 2 p.m. to 3 p.m. for two-way traffic, periods which may differ in other cities. The individual work of one car is given in Table 2.

14 The overbalance of these machines is about 800 lb. of live load and is reduced by the weight of the operator to 660 lb. of actual passenger load. The excess or overbalance of the actual mean passenger loads thus becomes 520 lb. for 3 hr., 400 lb. for 4 hr., 310 lb. for 5 hr., indicating that an unnecessary amount of overbalance is provided and that improvement could be effected by reduction of the counterbalance.

15 In hydraulic-cylinder elevators, and notably in those of the plunger type, the absence of counterbalance of the live load not only varies the period of acceleration and retardation to a wide extent, but as the power applied to these machines is fixed in extent, successive increments of load also vary the traveling speed. On a test of the very powerful hydraulic-cylinder elevators of the Hanover Bank Building, the traveling speed both up and down varied from 880 ft. per min. with a live load of 550 lb. to 330 ft. per min. with a live load of 3300 lb. The characteristics of the functions of stopping and starting varied as shown in Table 3.

16 In the plunger type of machine, the effects just described are increased on account of the large mass of material and water which must be set in motion to and arrested from the same speed as the car and the result is that both the period and the distance of acceleration and retardation are relatively prolonged. These effects are largely negatived in the electrical elevator, even where, as in the case of the traction type, the ropes and the counterweight all travel at the car-speed. This result is obtained by the introduction of the electrical and mechanical brake action in retardation, and by the ability of the electric motor to exert force in acceleration and motion approximating the resistance of its load. These capabilities have been very

[1] Elevator Service, published by the Author.

highly developed in the one-to-one traction electrical elevator, in which motors of large proportions accompany its relatively slow speed and the physical danger of dislodging the cables from the head sheaves by rapid retardation on the up run or of putting excessive strain on the cables in downward retardation are overcome by the arrangement of the friction drive. This form of machine therefore offers the largest possibilities in the directions discussed, affording maximum powers of acceleration at designed speed with all loads, and safe retardation.

17 But even with these powers, it will remain a fact that if the traffic in any elevator be such as to demand a stoppage within a distance less than that occupied by the operations of acceleration and

TABLE 3 TESTS AT HANOVER BANK BUILDING

LOADS, FUNCTIONAL DISTANCES AND SPEEDS

Live Load, Lb.	Speed, Ft. Per Min.	Acceleration Up Retardation Down, Ft.	Retardation Up Acceleration Down, Ft.	Functional Distance. Ft.	Mean Speed in 24 Ft. Per Sec.
3300	330	11	6.6	17.6	2
2200	625	7.25	7.75	15	7.15
1100	800	6.1	12.3	18.4	8.1
550	880	5	24	29	6

retardation, or what has been described as the functional distance, the designed speed will not be attained. Therefore, unless the number of elevators be so related to the traffic as to afford an average distance between stops in excess of the functional distance, there is no advantage derived from the designed speed. As high rates of designed speed involve proportionate forces, which in each type require either high pressure of power supply or large proportions of apparatus, it will be seen that substantial economy in first cost may be secured by so proportioning the elevators to their work that the best results may be attained with the most moderate designed speed.

18 In all elevators, particularly in those electrically operated, the use of power increases in proportion to the number of starts and stops. This is a natural result of the use of the electric motor, in which the largest part of the energy is required for the process of first motion and acceleration, the next largest for electrical and mechanical retardation, and a lesser amount for the actual running speed, with a small proportion devoted to the continuous excitation of the field. It therefore follows that in this form of elevator, which is now so widely used, the main part of the consumption of power is directly related to the number of stops and starts which accompany and result

from the number of persons carried. The diversities in results which have been reported from time to time as to the consumption of current by electrical elevators may be attributed to variations in traffic conditions.

19 A series of very interesting tests were recently made upon the operation of a one-to-one traction elevator in the ten-story building of the Boston Edison Company, in which observations of the use of current were made at varying numbers of stops and starts with various loads.

TABLE 4 CURRENT CONSUMED BY AN ELECTRIC ELEVATOR AT VARIOUS LOADS AND STOPS

Floors		Up	Bt.–10	1–9	1–9	1–9	1–9
		Down	10–Bt.	9–1	9–1	9–1	9–1
Distance, Ft.		Up	124.6	101.5	101.5	101.5	101.5
		Both Ways	249.2	203	203	203	203
Stops		Up	Bt.–10	1–9	1,5,9	1,3,5.7,9	1,2,3,4,5,6,7,8,9
		Down	10–Bt.	9–1	9,5,1	9.7,5,3,1	9,8,7,6,5,4,3,2,1
		Total	2	2	4	8	16
		Per Mile	42 4	52	104	208	416
Load in Car, Lb.	Operator Only	Kw-Hr. per Car-Mile	2 321	2.181	3.05	2.366	7.95
	666		2.855	2.54	2.51	2 2	6.83
	1060		....	2.2	3.34	4.65	6.8
	2010		....	2.4	3.16	5.0	7.97
	2660		....	2.93	4.16	....	....

Machine: Otis electric traction elevator
Capacity: 2500 lb. at a speed of 500-550 ft. per min.
Balance: 1060 lb.; 200 volts, direct-current
Date of test: December 1909
Place: Boston, Mass.

20 The writer has plotted from these results a series of curves shown in Fig. 5 which indicate very clearly that at all loads an increase in the number of stops results in a progressive increase in the current consumption. The shape of all these curves is affected by the relation of the overbalance to the load and at or near the balance point the most efficient service is naturally attained.

21 In hydraulic elevators the cost in energy of stops and starts is that of the water under pressure, which is used for the reversal of the valves. In a test of the plunger elevators in the United States Express Building, in which the writer took part, the proportion of water thus used in stops and starts was ascertained to be, on the basis of four stops up and four stops down to ten floors above the ground, 11.1 per cent of plunger displacement, and on the basis of a stop at every floor up and down, 22.2 per cent.

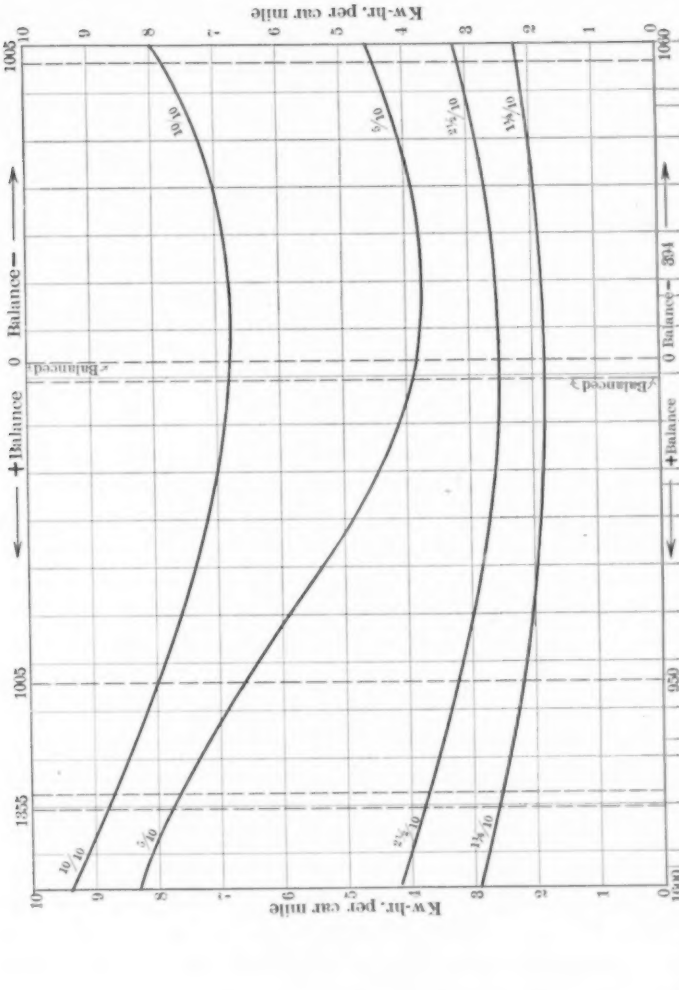


FIG. 5 CURRENT CONSUMPTION OF ELECTRIC ELEVATORS AT VARIOUS LOADS AND STOPS

22 The method employed by the author in securing data bearing on these subjects is the observation of the number of persons carried each way on each trip by each elevator in a given time. Such observ-

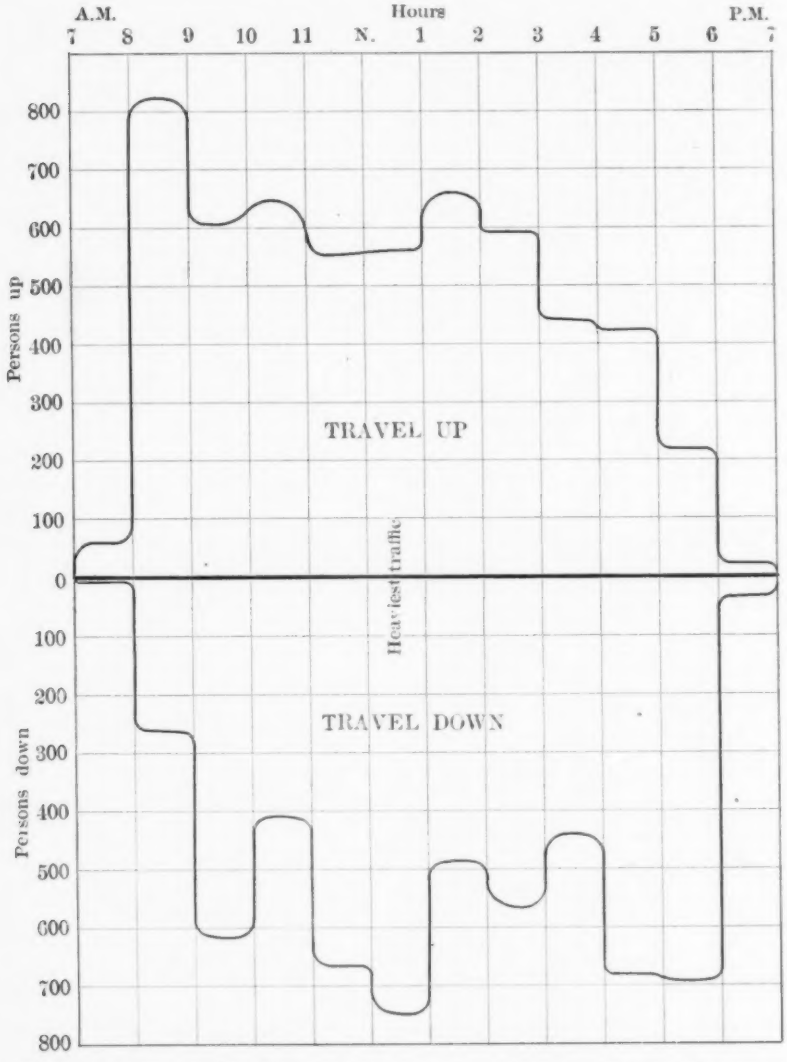


FIG. 6 FLOW OF ELEVATOR TRAFFIC IN A CHICAGO OFFICE BUILDING

ations have been taken in a number of buildings of widely differing proportions and characters, in cities as far apart as Seattle and Atlanta,

and as diverse in characteristics as Detroit and Portland, Ore. In all cases these tests have proved of value by indicating opportunities for improvement in service and in economy and have also confirmed the foregoing conclusions as to the influence of traffic upon speed and efficiency of service.

23 An interesting and comprehensive example of this method of observation is that afforded by the six hydraulic elevators of a Chicago office building of 17 stories located in the heart of the business district and having a professional, business and brokerage tenantry. The results of these observations are plotted in diagramatic form in Figs. 6, 7 and 8. The upward and downward traffic is plotted vertically above and below the middle horizontal line and the period of service is shown on the horizontal scale. In Fig. 6 the total combined hourly traffic each way is shown and from it is observable the disposition of traffic during the hours of business, the heaviest period being for one-way traffic from 8 to 9 a.m. and for two-way traffic from noon to 1 p.m. The total combined traffic for the day's service was 5888 persons carried up and 5801 carried down.

24 In Fig. 7 the combined schedule work of the six cars is plotted, showing the number of persons lifted or lowered by all six cars on each schedule movement, affording a picture of the response of schedule operation to the flow of traffic. The average total of the six cars per hour is shown in the double dotted line on the upper and lower part of the scale, and the average number of persons per hour per car is shown in the strong single dotted line. The average number of persons carried per car per hour was 5 up, 4.91 down, and 4.95 each way. The total each way per hour aggregated 584 persons.

25 Fig. 8 shows the work of these cars in still greater detail, the six diagrams giving the individual work of each car per trip, affording a complete picture of the division of the work between the several cars. Several interesting observations can be made from this diagram. The best work of the day was found to have been done by car No. 2, which during the busy hour of noon to 1 p.m. carried 264 persons, or a mean of 6.6 each way per trip. The heaviest day's work was done by car No. 5, which carried an average of 5.34 persons each way in the average round-trip time of 3.07 min. The average round-trip time of the schedule as maintained was 3.09 min., and the best time for an individual car was that of car No. 2 which made certain trips in 2.5 min. round-trip time, carrying 4.35 persons each way, at the rate of 104 persons per hour.

26 It will be observed that at various times the operation of car No. 3 and car No. 6 was interrupted by their diversion from the service for freight purposes, and at the particularly busy time near one o'clock, when this occurrence took place on car No. 3, the traffic was forced into the other cars, the loads on which were greatly increased, with the result that the number of round-trips made by those cars was reduced.

27 The division of passenger time and machine time in these cars was ascertained by observations of the speed of two of the cars with a live load of three passengers each way. On a run from top to bottom of the shaft, the speed developed under those conditions, was 6.77 ft. per sec., corresponding to a designed speed of 400 ft. per min. With the same load, but starting and stopping at every alternate floor, the mean speed fell to 4.8 ft. per sec. As the schedule maintained by the service allowed an interval between arrival and departure of cars at the ground floor of 30.9 sec., the actual time of the average trip became 154.5 sec. The average speed of 4.8 ft. occupies 80 sec., leaving for passenger time, less the top landing, 65.5 sec. The average number of persons carried by two of the cars when operating at this speed was 6.6 each way, or 13.2 in all, so that the passenger time was 5 sec. per passenger per landing, which is the allowance to which reference was previously made.

28 These observations indicated further that the elevators were capable of handling the busy-hour traffic at the rate of four landings to ten floors and were operated under an average of three and one-tenth stops to ten floors, affording an ample service readily capable of meeting the variations in the flow of traffic. They also indicated that during the heaviest period of the day when the relation was increased by the withdrawal of one car, the time of the round trip was delayed and the schedule lengthened, reducing the convenience and the efficiency of the service.

A NEW THEORY OF BELT DRIVING

By Selby Haar,[1] Schenectady, N. Y.

Non-Member

While investigating the subject of belt efficiency the writer found a theory of the transmission of power by leather belting so different from the one generally accepted in the United States that the original purpose of the investigation became of secondary importance. It is not claimed that everything to be presented in this paper is new; in fact, many of the conclusions which will be drawn have already been brought before the Society. It is believed, however, that considerable novelty will be found in many of the opinions cited. Since the accepted theory can be so easily found in reference books, no complete exposition will be attempted here.

2 When a belt is stretched over a pair of pulleys at rest, the tension in both strands is the same, and is due solely to the elasticity of the material. When the pulleys are set in motion and power is transmitted through the belt from one to the other, the tension in the tight side increases while the tension in the slack side decreases, their difference being the so-called "effective pull," which is a measure of the power transmitted. It is known, however, that the sum of the tensions does not remain constant. Since the belt is prevented from sliding on the pulley by virtue of the frictional resistance, a great deal of study has been given to the determination of the coefficient of friction. If T_1 is the gross pull on the tight side, and T_2 the gross pull on the slack side, we obtain the relation $\frac{T_1}{T_2} = e^{f\alpha}$, where e is the base of the natural system of logarithms, f is the coefficient of friction, and α is the circular measure of the smaller arc of contact on the two pulleys. This assumes that f is a constant and that the tension in the belt increases uniformly along the arc of contact; it neglects

[1] General Electric Company.

The American Society of Mechanical Engineers, 29 West 39th Street, New York. All papers are subject to revision.

also the reduction of the effective tension due to centrifugal force. Since T_1 is limited by the strength of the belt, the effective pull can be increased only by decreasing T_2. If the arc of contact α cannot be changed on account of the diameters or locations of pulleys, the only factor susceptible of variation is f, the coefficient of friction. Most of the familiar methods for increasing the pulling power of a belt depend on an increase, artificial or natural, in the coefficient. It is for this reason that in this country paper and wood pulleys are crowding out iron ones. While $f = 0.4$ is frequently given for leather belts on cast-iron pulleys, $f = 0.65$ is claimed for paper pulleys. Quite a common assumption is that $\frac{T_1}{T_2} = 3$. This brings $f = 0.35$ for $\alpha = 180$ deg., and $f = 0.382$ for $\alpha = 165$ deg. Kent,[1] gives a table based on $f = 0.40$ and $\alpha = 180$ deg., to which is added a table of corrections for other arcs of contact. Several designs for idlers have been developed, which are intended to increase the arc of contact. Furthermore, the introduction of belting made of steel is a step in the direction of increasing T_1. The complete theory makes allowance for the centrifugal force of the belt by reducing the effective

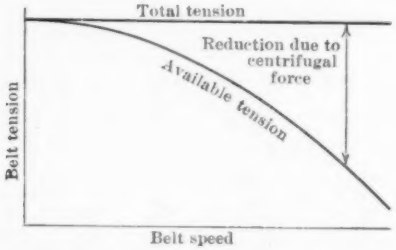


FIG. 1 REDUCTION OF BELT TENSION BY CENTRIFUGAL FORCE

tension on both the tight and the loose sides. This counteracting component is $\frac{wv^2}{32.2}$, where w is the weight of a piece of belt 1 ft.long, and 1 in. wide, and v is the belt speed in ft. per sec. The complete expression is $\frac{T_1 - \frac{wv^2}{32.2}}{T_2 - \frac{wv^2}{32.2}} = e^{f\alpha}$, according to which the net allowable tension in the belt decreases as the square of the speed. Fig. 1 shows

[1] Mechanical Engineers' Pocketbook.

graphically the calculated reduction. So much for the present theory, from which the new theory now diverges.

3 In 1893, C. Otto Gehrckens[1] published a table of empirical con-

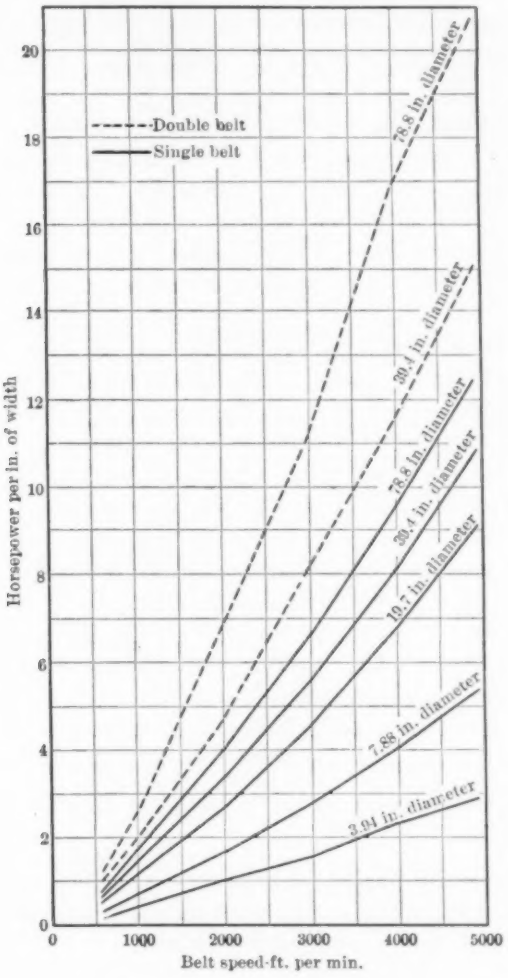


FIG. 2 SAFE LOADS ON BELTS

stants derived from experience, giving the effective pull to be allowed in belts, in which the following noteworthy features are contained: the allowable effective pull increases with the speed; at constant speed

[1] Zeitschrift des Vereines deutscher Ingenieure, 1893, p. 15.

the load increases with the diameter of the pulley. Fig. 2, which has been calculated from these constants and converted to English units is inserted to show their general tendency. The curve for a double belt on a 500-mm. (19.7-in.) pulley has been omitted for clearness. The tables and the curves show that a double belt should not be expected to carry twice as much as a single belt. This agrees with our practice.

4 The argument by which Mr. Gehrckens defends these constants is as follows: The leather in the tight side of the belt tends to stretch because of the tension and to contract again when it passes over to the slack side. This successive expansion and contraction occurs in a slowly moving belt, but at high speeds the alternation of position is so rapid that there is not time for the belt to assume a strain corresponding to the stress. As a result the condition of equilibrium is found to be a stretch corresponding to some value of tension less than the actual maximum. The stretch being the limiting condition, the apparent tension in the tight side can be increased with the speed. Professor Bird[1] in his paper on Belt Creep also mentioned this feature of time lag. The larger constants for pulleys of large diameter are explained by the smaller bending stress caused by the curvature. By a series of over 1000 tests on belt transmission, Professor Kammerer[2] of Charlottenburg confirmed this theory completely and Fig. 3 shows his recommendations. This curve is based on $f = 0.5$ and $e^{f\alpha} = 3.5$, from which we deduce that the effective pull is 0.7 of the available tension. It will be noted that even at a speed of 8000 ft. per min. the effective pull has not reached its maximum. His research also included extensive measurements of the coefficient of friction and belt creep, a fuller account of which follows. A description at this point of the testing apparatus may make the discussion of his results clearer.

5 Upon a steel girder base were mounted two heavy cast-iron frames: one, the measuring head, moved on 16 hardened steel balls in grooves so as to reduce friction as much as possible and to compel a movement always truly parallel; and the other, the straining head, rested on a planed surface and was moved by a pair of chains. It was realized that it would be impossible to balance the pulleys perfectly and the frames were purposely made heavy in order to absorb and damp out the vibrations which were expected to occur at high speeds. Each belt-pulley shaft was mounted on two ball bearings to insure reduced and more constant friction and carried at each end the overhung armature of

[1] Trans. Am.Soc.M.E., vol. 26, p. 584.

[2] Mitteilungen über Forschungsarbeiten, Heft 56–57.

an electric motor. By the use of the two motors the load on the shaft was made symmetrical. This design of the equipment involves the minimum number of bearings with their uncertain friction, and avoids all couplings for transmitting the power.

6 For measuring the belt pull two liquid-pressure dynamometers like those used by Lieutenant Emery were provided, together with a set of pressure gages of suitable ranges. A dynamometer was placed on each side of the pulley on the outer end of the measuring head. Scales and spring dynamometers were rejected because it was feared that the rapid variations of the belt pull

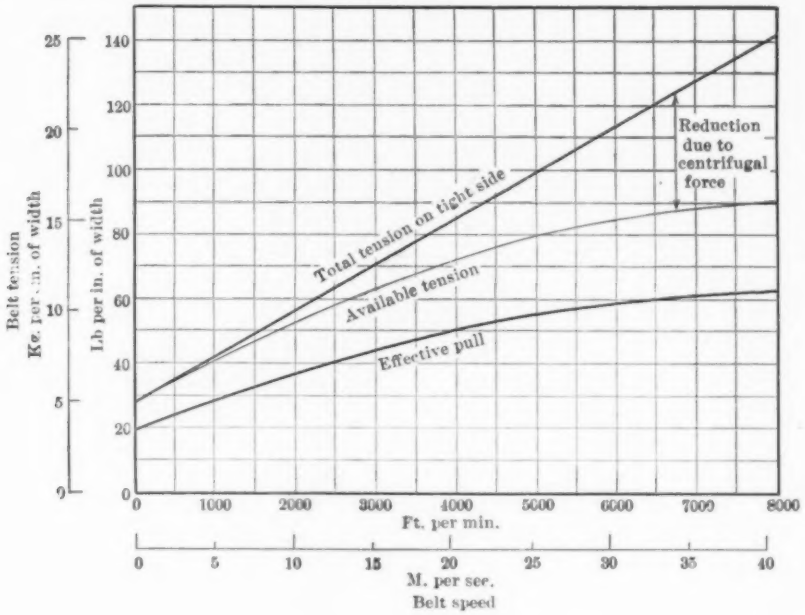


FIG. 3 RECOMMENDED LOADS FOR SINGLE LEATHER BELT

would make the readings unsteady. Belt creep was measured by revolution counters attached to the shaft, simultaneous starting and stopping being accomplished by the use of electromagnets, The creep thus measured was the total for both pulleys. The electrical readings consisted of the input to one pair of machines used as motors and the output of the pair on the other shaft used as generators.

7 The two motors on a shaft were run as a motor-generator set (with belt off the pulley) for the purpose of determining their efficiencies. The dynamometers were calibrated by a standardized tension bar from the Reichsanstalt. This bar was expensive and steel bands attached to the two carriages, loaded in the center and adjusted for constant deflection at the center, were substituted. This method checked well with the other.

8 The following pulleys were used: 2500 mm. (98.5 in.) in diameter and 400 mm. (15.75 in.) wide; 1250 mm. (49.2 in.) in diameter and 600 mm. (23.6 in.

wide; 600 mm. (23.6 in.) in diameter and 1000 mm. (39.4 in.) wide. The distance between centers of pulleys could be adjusted between the limits of 5000 mm. (197 in.) and 7500 mm. (295 in.). Both cast iron and wood were used for the 600-mm. pulleys; all the others were built up of structural steel. Two belts were used for most of the tests: a single belt 375 mm. (14.76) in. wide and 3 to 4 mm. (0.12 to 0.15 in.) thick; and a double belt 400 mm. (15.75) in. wide and 7 to 8 mm. (0.28 to 0.32 in.) thick. The single belt weighed 1.25 kg. per m. (0.84 lb. per ft.) and the double one 2.45 kg. per m. (1.65 lb. per ft.). Both were carefully selected and tanned. The tests with an idler were conducted on a single belt 150 mm. (5.9 in.) wide, 5 mm. (0.2 in.) thick, weighing 0.69 kg. per m. (0.46 lb. per ft.).

9 The modulus of elasticity of each complete belt was measured with the belt on the pulleys and running at a low speed. The tension was read on the dynamometers and the stretch was obtained from the displacement of the straining head. Readings were taken at intervals of two minutes and after each

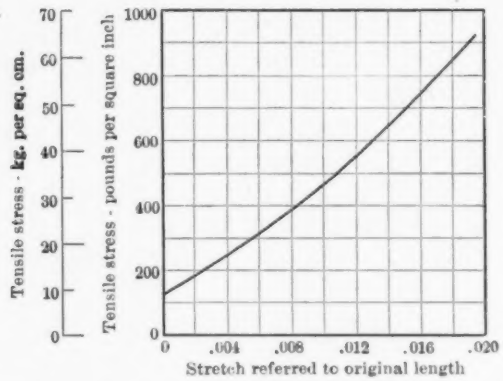


FIG. 4 STRESS-STRAIN DIAGRAM FOR SINGLE LEATHER BELT

reading the load was reduced to the initial value. The modulus of the single belt increased from 2500 kg. per sq. cm. (35,500 lb. per sq. in.) to 3520 kg. per sq. cm. (50,000 lb. per sq. in.), with an average value of 3000 kg. per sq. cm. (42,600 lb. per sq. in.) (See Fig. 4). The double belt showed an average modulus of elasticity of 2000 kg. per sq. cm. (28,500 lb. per sq. in.). Quite a perceptible permanent set was noticed. The average modulus of elasticity of the third belt was 1250 kg. per cm. (17,800 lb. per sq. in.). Professor Goodman[1] gives 8000 to 10,000 lb. per sq. in. for the modulus and Professor Bird[2] reports 12,000 to 30,000 lb. per sq. in. His comment is that E increases with the tension when the belt is running and is probably larger the greater the speed. Belt speeds varied from 9.56 m. per sec. (1880 ft. per min.) to 60.35 m. per sec. (11,900 ft. per min.). The range of speeds and loads was limited by restricting the tension in the tight side to 30 kg. per sq. cm. (420 lb. per sq. in.).

[1] Mechanics Applied to Engineering.

[2] Trans. Am.Soc.M.E., vol. 26, p. 584.

FOLDER NO. 1

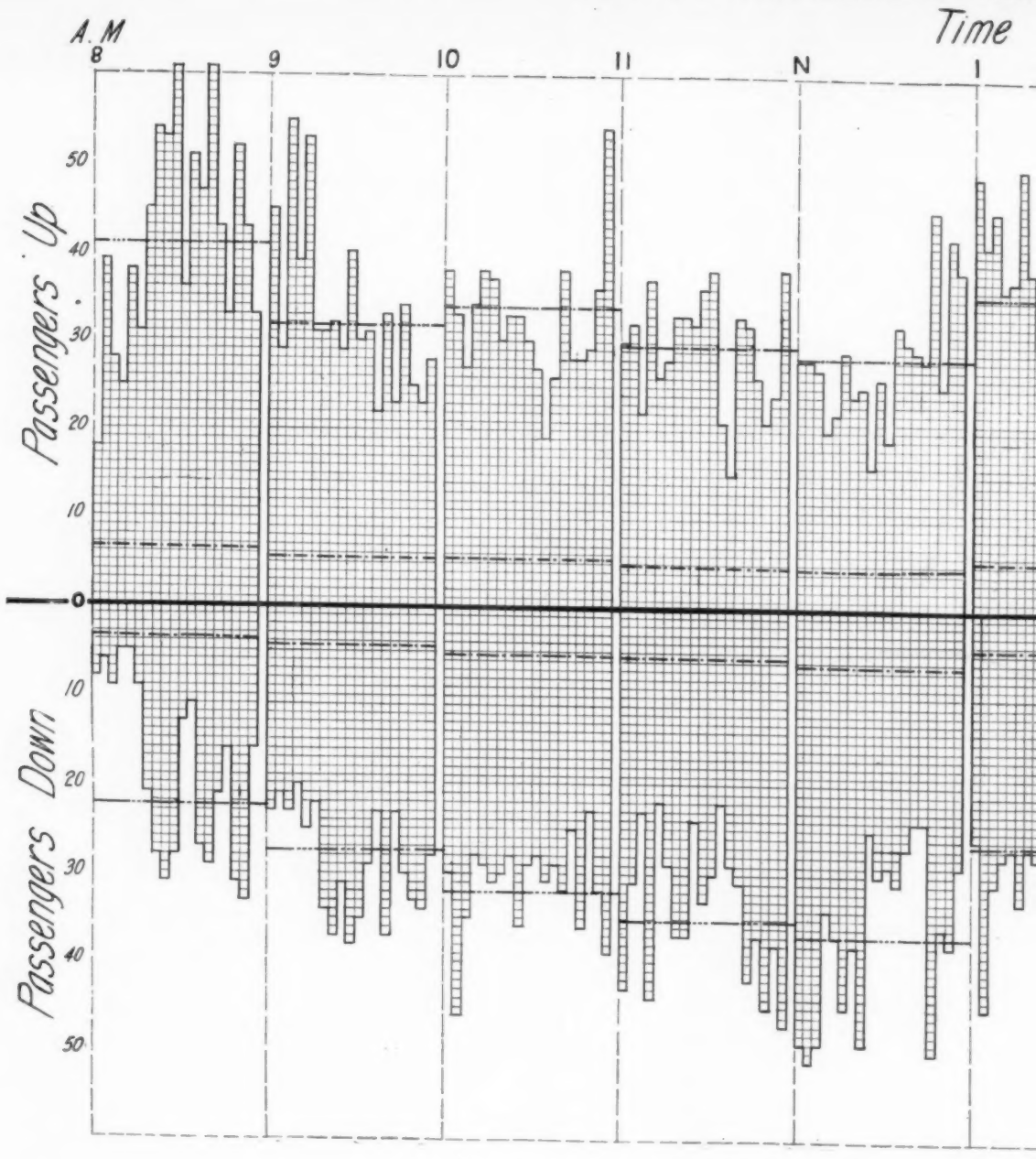
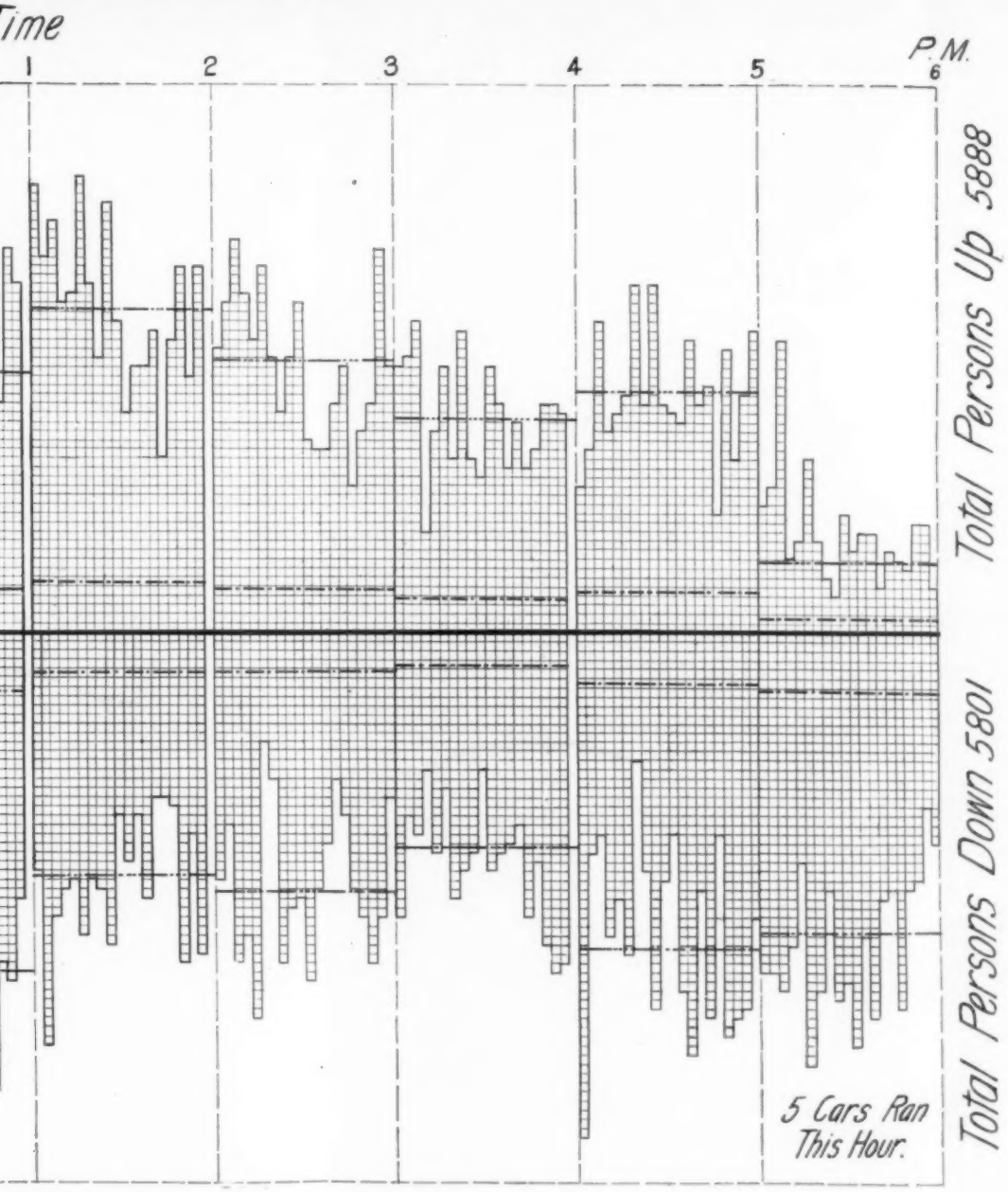


FIG. 7 COMBINED TRAFFIC OF SIX ELEVATORS IN A 16-S



Average Total Each Way Per Hour - 584 Passengers
Average Round Trip Time - 3 Minutes

RS IN A 16-STORY OFFICE BUILDING (SEE PAR. 24)

FOLDER No. 2

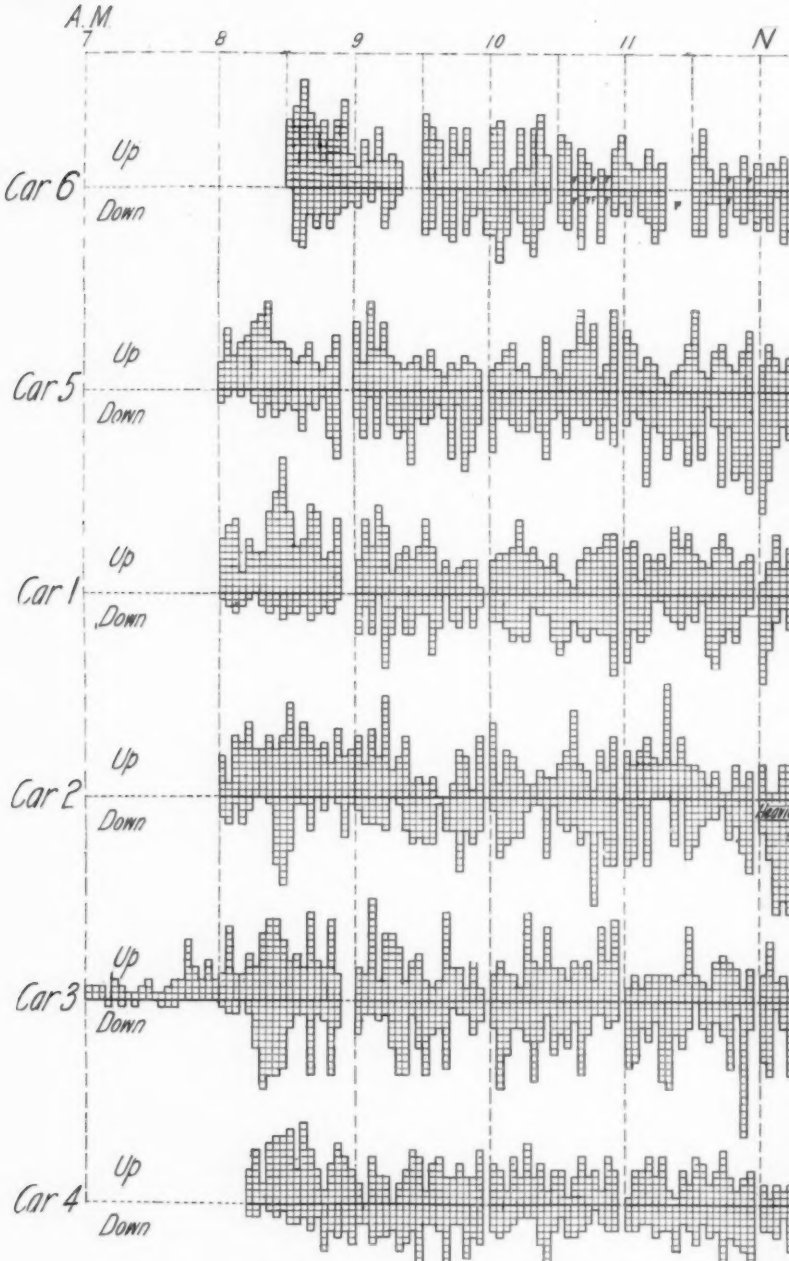
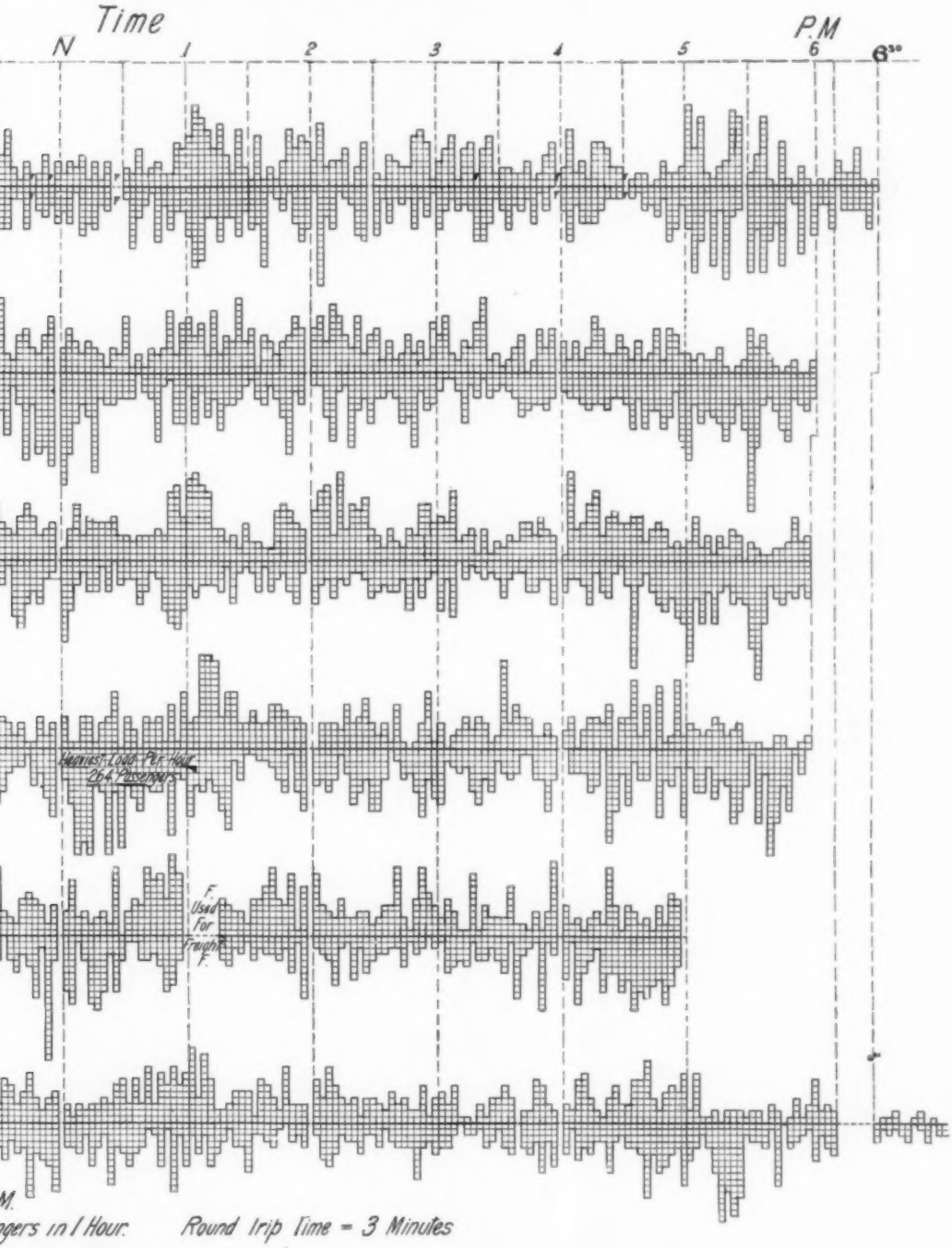


FIG. 8 TRAFFIC OF INDIVIDUAL ELEV

NDITIONS OF PASSENGER ELEVATORS



UAL ELEVATORS IN A 16-STORY OFFICE BUILDING. (PAR. 25).

In the light of the knowledge gained from the tests, the future experiments will not be limited by the belt tension, but by a permanent stretch in the belt within 30 min., as indicated by the dynamometer.

10 The following conclusions were drawn from the tests by Prof. Kammerer:

a The effective pull on a belt is not reduced so much by centrifugal force as the currently accepted method of calculation would lead one to expect. In other words, the maximum allowable tension in a belt apparently increases with the speed.

b The coefficient of friction increases with the speed and reaches values far above that usually assumed.

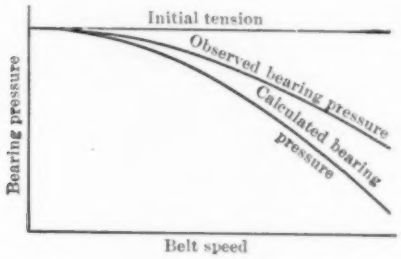


FIG. 5 EFFECT OF CENTRIFUGAL FORCE ON A BELT UNDER LOAD

c The maximum efficiency of transmission is not limited by the speed.

d The coefficient of friction is larger for large pulleys than for smaller ones.

e A wooden pulley has a higher coefficient of friction than an iron one, at least when new.

f Transmission is more efficient and the coefficient of friction is higher when the smaller pulley drives.

g A belt operates with higher efficiency and usually with less creep when the tight side is on the bottom.

h A properly placed idler improves the efficiency of transmission.

i The neutral layer is symmetrically located in the belt so that the effective diameter is the sum of the pulley diameter and the thickness of the belt.

j At any speed the sum of initial tension and centrifugal force is constant.

11 In connection with conclusion *a*, Fig. 5 is reproduced from Professor Kammerer's report, which confirms the statement previously made. The second method of stating the fact permits of a simpler calculation of the effective pull. It was found that for a single belt a working tension of 5 kg. per cm. (28 lb. per in.) of width at standstill could be increased to 25 kg. per cm. (140 lb. per in.) of width at 40 m. per sec. (7860 ft. per min.). (See Fig. 3). Fig. 6, which is a record of measurements made on the same belt when not transmitting power, shows that the calculated belt pull agrees substantially with

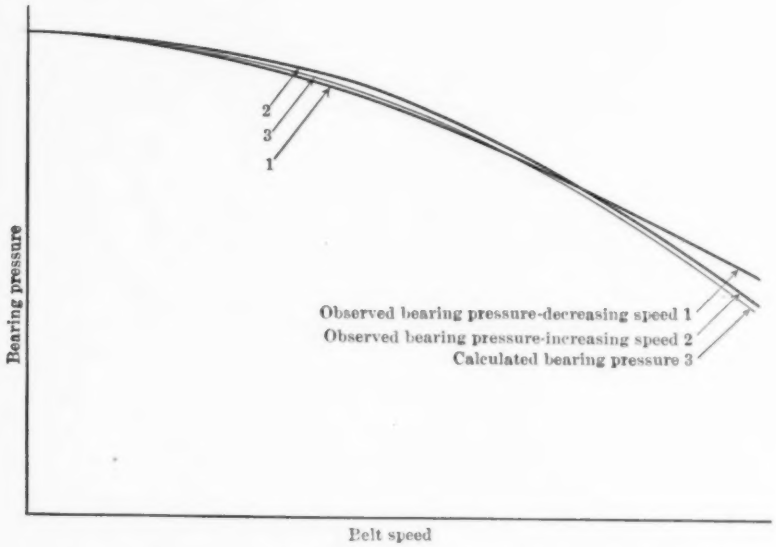


FIG. 6 EFFECT OF CENTRIFUGAL FORCE ON AN UNLOADED BELT

the measurements. Professor Kammerer's explanation of this phenomenon (unexpectedly low decrease in bearing pressure) has been sharply criticised by L. Benjamin,[1] who asserts that the reduced belt pull is due to the actual speed of the belt at the pulley being much higher than the average value. He claims that on account of the time lag between the tension and the stretch, the change in stretch resulting from the change in tension as the belt goes around the pulley does not occur until after the belt has left the pulley. The combination of the stretch and the translation of the belt causes a regular

[1] Zeitschrift des Vereines deutscher Ingenieure, 1909, p. 655.

change in its velocity as it travels between the pulleys. This means that the velocity of the tight side as it passes on to the driving pulley is considerably above the average and since the speed is higher, the effective pull must be less.

12 Alexander Fieber,[1] by means of a tachometer similar to the cut meter, measured the speed at various points along a rubber belt running at an average speed of 5.04 m. per sec. (990 ft. per min.) with a creep of 15 per cent, and an average speed of 5.245 m. per sec. (1030 ft. per min.) with a creep of 5.5 per cent.

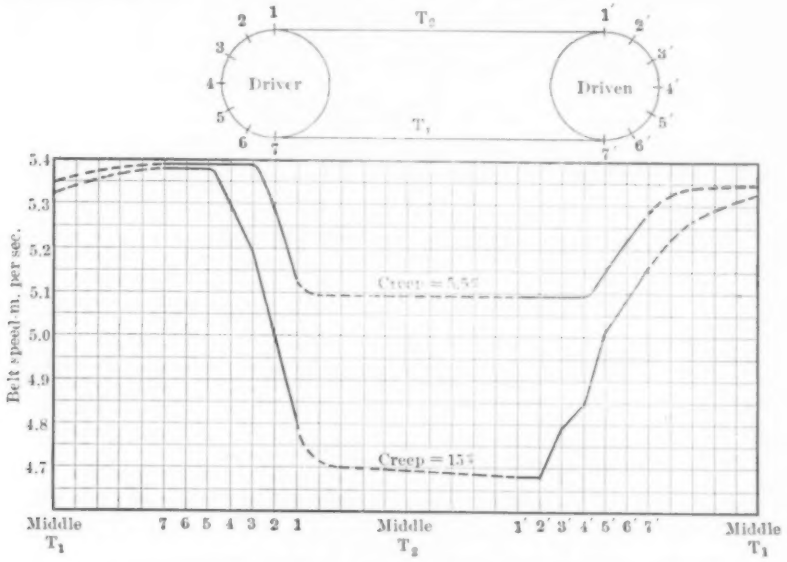


FIG. 7 VARIATION OF SPEED ALONG A BELT TRANSMITTING POWER

The belt was of best Para rubber, 3500 mm. (138 in.) long, 100 mm. (3.94 in.) wide, 6 mm. (0.236 in.) thick. The pulleys were 1700 mm. (67 in.) apart. The average speed was obtained by observing the motion of a chalk mark on the belt. Fig. 7 is a reproduction of these curves, and confirms Mr. Benjamin's contention that the belt speed changes regularly between the pulleys. Professor Kammerer repeated the measurements on a leather belt on pulleys running at 20 m. per sec. (3940 ft. per min.). It was a double belt 90 mm. (3.54 in.) wide, with the tight side on top. The initial tension was 17 kg. per cm. (95 lb. per in.), and the effective pull was 22 kg. per cm. (123 lb. per in.). Both pulleys were 2500 mm. (98.5 in.) in diameter and were 6300 mm. (248 in.) apart. To determine the speeds he used a wheel connected to a revolution counter, which was held at any point for 6 min.

[1] Zeitschrift des Vereines deutscher Ingenieure, 1909, p. 1641.

Fig. 8* shows the measurements he reported. He found that the difference between the speeds of the tight and the loose sides of the belt was only 1.1 per cent, which is quite insufficient to account for the increased capacity observed.

13 The coefficient of friction was calculated from the geometrical arc of contact and the tensions in the belt as deduced from the load and belt pull; this is necessarily an average value, as the formula assumes a regular increase of creep over the whole arc of contact. With arcs of contact of 160 deg. to 175 deg., maximum values of 0.5 to 0.8 were calculated. The value usually assumed, 0.28, should be compared with these, and also 0.35 which was obtained for 10 kg. per cm. (56 lb. per in.) by reducing the load on a slipping belt until the motion stopped, the pulley being stationary. The high values of

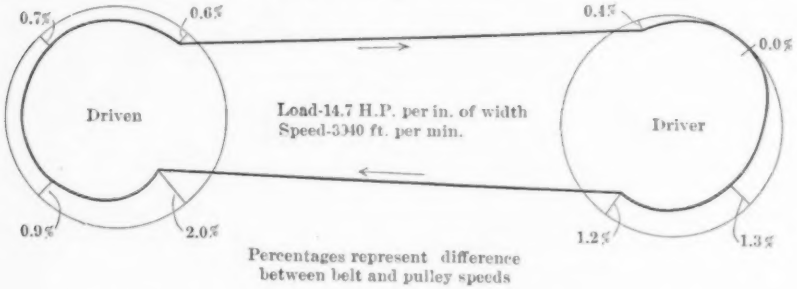


FIG. 8 VARIATION OF SPEED ALONG A BELT TRANSMITTING POWER

f calculated under certain conditions led to the belief that the continual creep of the belt on the pulley produced a partial vacuum between them. Mr. Gehrckens[1] disagrees with this, however. The coefficient becomes very large when T_2 approaches zero. Mr. Wilfred Lewis has reported values well over 1. Mr. Gehrckens[2] says that at high speeds, say over 50 m. per sec. (9800 ft. per min.) the tension in the slack side can be not only zero, but negative, so that the slack side is not pulled along, but is hurled upon the driven pulley and shoots out over it, as actually happens. The well marked undulation in the slack side is probably started in this way which persists when once started, so that it appears as if the belt were running in the opposite direction from the pulley. For such a case a new formula would have to be developed.

* Zeitschrift des Vereines deutscher Ingenieure, 1909, p. 1642.
[1] Zeitschrift des Vereines deutscher Ingenieure, 1908, p. 1443.
[2] Zeitschrift des Vereines deutscher Ingenieure, 1909, p. 1820.

14 Mr. Barth[1] gives an expression for f which involves the speed. Professor Kammerer's curves apparently show that f increases with the speed. Another feature influencing the value of f is clearly shown in Fig. 7. This confirms the theory of Grashof that belt creep occurs only on part of the arc of contact, not on the whole of it. The measurements show a part of the pulley circumference over which the belt speed is constant and equal to that of the pulley, while over the rest of the arc of contact the speed changes rapidly. For the same T_1 and T_2, the arc of creep is the same. When the belt is just on the point of slipping off, the arc of creep becomes equal to the arc of contact. E. A. Brauer[2] calls attention to the same phenomenon and says it can easily be shown as a lecture-room experiment. Since different values for f, 0.4 and 0.35, were found for the belt stationary with respect to the pulley, and when slipping over it, the adoption of this assumption would give a still different set of values for f.

15 The efficiency, which should be understood to include the losses in the belt only, was the same at 26.5 m. per sec. (5200 ft. per min.) as at half speed in a certain test. The value 0.98 was reached in each case, but naturally not at the same load.

16 Comparisons of values of the coefficient of friction show that they range a little higher for large pulleys than for smaller ones.

17 American tests confirm the superiority found for wood pulleys but Mr. Gehrckens warns us that belts do not last as long on wood pulleys as on iron. Paper pulleys show a higher coefficient of friction than wood.

18 Differences of over one per cent in efficiency and 0.05 to 0.15 in f were found for the same pulleys and loads, when transmitting from low to high shaft speed or the reverse, the most economical transmission occurring with the higher speed shaft (and smaller pulley) as driver.

19 American practice also calls for the tight side of the belt on the bottom, but the idler is usually not favored. Unquestionably the reverse bending of the belt does not tend to prolong its life, but in some cases the arc of contact can be increased sufficiently so that the effect of the reduced initial tension may counterbalance the depreciating tendency of the reverse bending. The idler used in the tests operated on the slack side of the belt and was carried by a swinging frame which could be screwed down to produce the tension.

[1] Trans.Am.Soc.M.E., vol. 31, p. 29.

[2] Zeitschrift des Vereines deutscher Ingenieure, 1908, p. 965.

20 The conclusion that the neutral layer of a belt is symmetrically located is generally accepted, although Professor Bach has given $D + \frac{2}{3} S$ as the effective diameter of a driving pulley, and $D + \frac{4}{3} S$ for a driven one (S = thickness of belt).

21 In consequence of the elasticity of the belt, its length and deflection between the pulleys is proportional to the stress which is a resultant of the weight of the belt, the initial tension, and the centrifugal force. The last is, of course, constant for any given speed and causes only a tensile strain in the belt, similar to hoop tension. Now if we construct an expression for the length of the belt, allowing for its stretch, it will be found that the sum of the initial tension and the centrifugal force is constant, as shown by Professor Kammerer.[1] This means that as the speed increases, the initial tension is replaced by tension due to centrifugal force. As the centrifugal stress is absorbed in the belt and produces no bearing pressure, the increase in speed causes a decrease in bearing pressure.

22 Let us return to the efficiency of belt drives, which has been exhaustively discussed by Dr. K. Kobes[2] and by Dr. F. Niethammer,[3] by whom the results of an elaborate method of testing are reported. The losses to be taken into account are due to the stiffness of the belt, creeping on the pulley, thickness of the belt, and friction against the air.

23 *Stiffness.* Assume a belt of width b_1 (in.) and thickness S_1 (in.) running over a driving pulley D_1 (in.) in diameter at n_1 r.p.m., and a driven pulley D_2 (in.) in diameter at n_2 r.p.m. If the driving pulley delivers to the belt N_1 h.p. at a speed V_1 (ft. per min.) $= \pi D_1 n_1$, the effective pull is P_1 (lb.) $= \dfrac{N_1 \times 33{,}000}{V_1}$ at the pulley rim. The loss due to stiffness was found by Grove[4] to be represented by an expression which reduces in English units to

$$\Delta P_1 = 0.167\, E b_1 S_1 \left[\left(\frac{S_1}{D_1}\right)^2 + \left(\frac{S_1}{D_2}\right)^2 \right]$$

where E is the modulus of elasticity of the leather. This must be reduced to the pulley rim as Dr. Kobes subtracts it directly from

[1] Zeitschrift des Vereines deutscher Ingenieure, 1909, p. 1820.

[2] Zeitschrift des Oesterreichischen Ingenieure und Architekten-Vereines, 1908, Nos. 16, 47, 48.

[3] Zeitschrift des Vereines deutscher Ingenieure, 1908, p. 668.

[4] Einfache Maschinenteile, p. 263.

P_1. The relative loss is

$$\frac{\Delta P_1}{\frac{N_1 \times 33{,}000}{V_1}} = \frac{\Delta P_1 V_1}{33{,}000\, N_1}$$

and the partial efficiency is $1 - \frac{\Delta P_1 V_1}{33{,}000 N_1}$. Let $\frac{\Delta P_1 V_1}{33{,}000} = a$, then the efficiency is $1 - \frac{a}{N_1}$. Now as long as E and V_1 are constant, a is constant, so that the equation for efficiency is a rectangular hyperbola, according to which the efficiency increases continually with the load.

24 *Creep and Thickness.* Without creep the belt would have a uniform velocity throughout, and the speed of the driven pulley n_2' r.p.m. would be $n_2' = \frac{D_1 + S}{D_2 + S}$. The transmission of power necessarily involves creep, which is proportional to the effective tension on the unit area of cross-section, and the effect of creep is a loss of velocity. If ψ is a constant of proportionality, the ratio of creep to belt velocity is $\psi \frac{N_1 \times 33{,}000}{V_1 b_1 S_1}$ and the actual speed of pulley 2 is

$$n_2 = n_1 \frac{D_1 + S}{D_2 + S}\left(1 - \psi \frac{33{,}000}{V_1 b_1 S_1} N_1\right)$$

If we had also neglected the thickness of the belt, the speed of pulley 2 would have been $n_2'' = n_1 \frac{D_1}{D_2}$. Since there is no loss of pull between pulleys the efficiency is the ratio of actual to theoretical speed, or

$$\frac{n_2}{n_2''} = \frac{n_2}{n_1 \frac{D_1}{D_2}} = \frac{n_2}{n_1} \times \frac{D_2}{D_1} = \frac{D_2}{D_1} \times \frac{D_1 + S}{D_2 + S}\left(1 - \psi \frac{33{,}000}{V_1 b_1 S_1} N_1\right).$$

Now if $b = \frac{D_2}{D_1} \times \frac{D_1 + S}{D_2 + S}$ and $c = \frac{V_1 b_1 S_1}{33{,}000\, \psi}$, the partial efficiency $= b\left(\frac{N_1}{1 - c}\right)$ which is the equation of a straight line. The efficiency therefore deceases directly with the load.

25 *Air Resistance.* According to Zahm,[1] the frictional resistance

[1] Phil. Mag., 1904, vol. 2, p. 58.

R (lb.) on one side of a plate 1 ft. wide, l ft. long, at a relative air velocity of v ft. per sec. is $R = 0.00000778\, l^{0.93} v^{1.85}$. Using l instead of $l^{0.93}$ and taking e as the distance between centers of pulleys we have, for an open belt, a total resistance

$$R = 0.00000778 \left[4\left(b_1 + S_1\right) e + \left(b_1 + 2\,S_1\right)\left(D_1 + D_2\right)\frac{\pi}{2}\right]\left(\frac{V_1}{60}\right)^{1.85}$$

which gives a loss in horsepower of

$$N_a = \frac{0.00000778}{(60)^{2.85} \times 550}\left[4\left(b_1 + S_1\right) e + \left(b_1 + 2\,S_1\right)\left(D_1 + D_2\right)\frac{\pi}{2}\right] V_1^{2.85}$$

This contains only constant quantities when V_1 is constant and hence is independent of the load. When this loss is allowed for the total efficiency is obtained, the curve of which is an hyperbola.

26 The output, being the product of the efficiency and the input, follows an equation which is that of a parabola. If N_2 is the output in horsepower,

$$N_2 = b\left[\left(1 + \frac{a}{c}\right) N_1 - \left(a + \frac{N_a}{b}\right) - \frac{N_1^2}{c}\right]$$

The axis of the parabola is parallel to the output coördinate and passes through the point of maximum output, which has the coördinates $N_1 \text{ max.} = \dfrac{a + c}{2}$, $N_2 \text{ max.} = \dfrac{b}{c}\left(\dfrac{a - c}{2}\right)^2 - N_a$. The curves conform quite closely in general features to motor curves. The same value of output corresponds to two values of input in most cases, and the maximum output occurs at a greater load than the maximum efficiency. The largest component of the losses is the creep, so that the maximum output of a belt would occur at a creep of nearly 50 per cent. Therefore, the maximum output of a leather belt may be said to have no practical significance.

27 The constant ψ which occurs in the expression for the creep was found by test to be $\dfrac{1}{1100}$ in metric units or $\dfrac{1}{15{,}700}$ in English units. According to Grashof, $\dfrac{1}{\psi} = E$ so that tests show ψ twice as large as it should be. Possibly Grashof's formula refers to the creep on one pulley, whereas Professor Kammerer's measurements included both pulleys. Professor Bird gives an equation for creep of the form

$$\frac{\frac{P_1}{b_1 s_1}}{E + \frac{P_1}{b_1 s_1}} = \frac{V_1 - V_2}{V_1}$$

which is quite similar to the form used above.

28 The writer does not agree with the assumption of a loss due to the thickness of the belt, because it is not clear to him how such

TABLE 1 TEST RESULTS ON BELT EFFICIENCY

Delivered to Belt by Motor		Belt Loss	Efficiency of Belt	Effective Pull per Unit Width*	
Watts	H.p.	Watts		Kg. per Cm.	Lb. per In.
433	0.58	90	0.79	1.12	6.27
1456	1.95	90	0.938	2.91	16.3
2500	3.35	70	0.972	4.86	27.2
3640	4.88	75	0.979	7.07	39.6
4190	5.61	95	0.977	8.19	45.8
4810	6.45	100	0.979	9.56	53.5

*Belt speed at 1100 r.p.m. of generator, 17.3 m. per sec. (3400 ft. per min.)

TABLE 2 TEST RESULTS ON EFFECTIVE PULL

Motor r.p.m., Per Cent Above Generator r.p.m.	Effective Pull	
	Kg. per Cm.	Lb. per In.
2.45	9.7	54.3
1.73	8.0	44.8
1.18	5.44	30.4
0.91	2.9	16.2
0.45	0.8	4.48

a loss would be manifested, whether as heat or in some other way. There is an increase of effective pull at the face of the driven pulley to correspond to the decreased diameter as compared with the belt.

29 Professor Niethammer's tests, which have already been mentioned, were carried out in the following manner:

An electric motor was belted to a dynamo, both having pulleys of the same diameter, and an extended load test was run, the readings being taken with exceeding care. The pulleys were then removed, motor and dynamo were connected by a flexible coupling, and the tests were repeated, particular care being taken that the dynamo potential, current and speed were reproduced exactly as before. It was assumed then that the input to the dynamo was the same in

both tests. The motor was then disconnected and tested with a brake under proper conditions to determine its actual output in both the previous tests, the difference in motor output being taken as the loss in the belt. Two belts were used: one a single belt 30 mm. (1.18 in.) wide, 4.8 mm. (0.19 in.) thick; the other 68 mm. (2.68 in.) wide, otherwise the same. The narrow belt was new. The pulleys were 300 mm. (11.8 in.) in diameter and were 1900 mm. (75 in.) on centers. Table 1 has been prepared from figures given in the paper.

Attention is called to the fact that the belt loss is nearly constant, to the rapid rise of efficiency and to the extended range of the high values. For the sake of completeness Table 2, comprising the creep curve on both pulleys, has been included. This curve does not pass through the origin. Professor Kammerer reports an efficiency of over 0.98 for a speed of 13 m. per sec. (2560 ft. per min.) and an effective pull of about 5 kg. per cm. (28 lb. per in.), while the method developed above gives 97.3 per cent at 7.07 kg. per cm. effective pull. This calculation is given in Appendix No. 1.

30 It should be noted that no allowance is made for the increase in bearing friction due to the belt pull or to the weight of the brake.

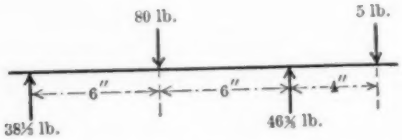


FIG. 9 LOADS AND BEARING REACTIONS DUE TO WEIGHTS

That this increased friction may not be inconsiderable will be shown by the following example. Assume a 5-h.p. motor running at 1100 r.p.m. with an armature weight and bearing spacing as shown in Fig. 9. Let the pulley weight be taken as 5 lb. The load on the right-hand bearing is $46\frac{2}{3}$ lb. and on the left-hand one $38\frac{1}{3}$ lb. With a coefficient of friction of 0.02 and a bearing diameter of $1\frac{1}{2}$ in., the bearing friction is approximately 16 watts. At a belt speed of 3400 ft. per min. the effective pull for 5 h.p. is 48.5 lb. The total belt pull may be taken as twice this, or 97 lb. The bearing reactions are $129\frac{1}{3}$ lb. for the right-hand side, and minus $32\frac{1}{3}$ for the left-hand side, as shown in Fig. 10. These latter loads are horizontal, while the weights act vertically; therefore they must be combined vectorially. The resultant bearing loads are $137\frac{1}{2}$ lb. and 50 lb. for the right and left-hand bearings respectively. If the coefficient of friction is 0.015, the friction loss is approximately 27 watts, an increase of 11 watts, which

occurs in both motor and generator, so that the total increase is 22 watts, which should be noticeable in a loss of 75 to 100 watts.

31 *Conclusion.* As a result of the modern experimental work on power transmission by leather belting, a great deal of light has been shed on the subject and the methods of treating it must be revised. It appears proved that the maximum allowable tension in a belt is not constant and neither is the belt velocity, even though the pulleys revolve at constant speed. The efficiency of a belt is shown to be quite high, just as high as a good gear transmission, the overall efficiency of the belt transmission being considerably reduced by larger bearing friction losses. This shows that the improvements should come in the bearings, as by the use of ball or roller bearings, for example. The exceptional flexibility of a belt transmission has made it

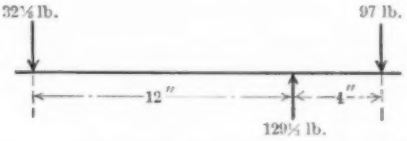


FIG. 10 LOADS AND BEARING REACTIONS DUE TO BELT PULLS

a favorite for many difficult problems. We shall close with the following remarkable—and, we are afraid, over-enthusiastic—prophecy of Mr. Gehrckens:[1]

Sixty m. per sec. (11,900 ft. per min.) is no limit to belt speeds at present. Belt pulleys have run at 500 m. per sec. (98,000 ft. per min.). Brown, Boveri and Company have reached 375 m. per sec. (74,000 ft. per min.); the Schuckert Company run flywheels at 100 m. per sec. (19,600 ft. per min.), (and so do American manufacturers).[2] Air resistance is an important feature at such speeds. When air is excluded the resistance decreases to one-half, and in a vacuum it is almost nothing. * * * We are by no means close to the limit of belt speeds, and the capacity of the belt does not commence to increase until high speeds are reached. Steam turbine speeds are so high that some reducing device must be provided and for this purpose the belt is the simplest and most practical connecting link. With transmissions at such high speeds the construction must be painstaking and the crowning of the pulley is an important feature.

[1] Zeitschrift des Vereines deutscher Ingenieure, 1908, p. 1444.

[2] Parenthetical expression is Mr. Haar's own comment.

APPENDIX NO. 1

CALCULATION OF BELT EFFICIENCY

32 *Example.* A motor delivers 4.88 h.p. to a belt 1.18 in. wide, 0.189 in. thick, running 3450 ft. per min. over pulleys 11.8 in. in diameter and 75 in. apart. The driven pulley makes 1100 r.p.m. What is the efficiency?

$$\Delta P_1 = 0.167 \times 31{,}300 \times 1.18 \times 0.189 \times \left[2 \times \left(\frac{0.189}{11.8}\right)^2\right] = 0.595 \text{ lb.}$$

$$a = \frac{0.595 \times 3450}{33{,}000} = 0.0621 \text{ h.p.}$$

$$b = 1$$

$$c = \frac{3450 \times 1.18 \times 0.189}{33{,}000 \times \frac{1}{15{,}700}} = 366 \text{ h.p.}$$

$$N_a = \frac{0.00000778}{(60)^{2.85} \times 550}\left[\frac{4\,(1.18 + 0.189)}{12} \times 6.25 + \left(\frac{1.18 + 0.378}{12}\right)\left(\frac{11.8 + 11.8}{12}\right)\frac{\pi}{2}\right](3450)^{2.85} = 0.00476 \text{ h.p.}$$

$$N_2 \text{ (output)} = \left[\left(1 + \frac{0.0621}{366}\right)4.88 - \left(0.0621 + \frac{0.00476}{1}\right) - \frac{(4.88)^2}{366}\right]$$

$$\text{Efficiency} = \frac{N_2}{N_1} = \frac{N_2}{4.88} = 1 + \frac{0.0621}{366} - \frac{0.0621 + 0.00476}{4.88} - \frac{4.88}{366} = 0.973$$

The loss is about equally divided between creep and stiffness, the air friction being negligible.

APPENDIX NO. 2

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NOTES ON THE VALUE OF NAPIER'S COEFFICIENT WITH SUPERHEATED STEAM

By Isaac Harter, Jr., Bayonne, N. J.

Associate Member of the Society

Owing to the fact that there do not appear to be any data on the value of Napier's coefficient with superheated steam, the writer is led to submit the results of some incidental observations made during the past year in connection with a series of tests run for a quite different purpose. The values recorded are for superheats between 45 and 195 deg. fahr., but unfortunately the entire series is confined to a quite narrow range of pressures, viz., between 138 and 148 lb. above the atmosphere.

2 The boiler used in these tests was fired with a chain-grate stoker and was fitted with a superheater of a special type, designed so as to conveniently secure various amounts of heating surface with practically constant superheat for each arrangement at a given boiler capacity. Each test was of five hours duration, preceded by a preliminary run of from four to five hours, depending upon the time necessary to bring the various observations to a constant state. A special feed line was used, the main feed being blocked by two valves with an open drain between. The boiler blow-off outlet was visible, and special care was taken to inspect all parts of the boiler before and after each test to make sure that there was no leakage. The water used was measured in two tanks, the contents of which could be read at any level within an error of 0.2 of 1 per cent. The feed water was regulated by a man stationed at the waterglass to within $\frac{1}{2}$ in. of a fixed height at all times and the water level was brought exactly to this fixed point at the close of each hour to secure hourly readings. An error of $\frac{1}{4}$ in. in water level at the close of any of these tests would have caused an error of 0.37 of 1 per cent, and considering the care

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taken, the probable error for any test was less than this amount. That the errors of observation were small is shown by the regularity with which the plotted results compare with an average curve drawn through them.

3 The diaphragm containing the orifice was placed at a short distance beyond the superheated outlet, and immediately below the diaphragm was placed a thermometer well and a connection for a pressure gage. The thermometer used at this point had a scale corrected for stem radiation. The pressure gage was furnished with a scale specially calibrated, and was in addition checked by means of interchange with other similar gages at other points on the boiler and by difference readings taken from time to time during the running of each test. The gages were also tested with a dead-weight apparatus a number of times during the series of tests.

4 The outlet beyond the diaphragm consisted of a fixed length of piping. Pressure readings taken just beyond the diaphragm showed 3 lb. above the atmosphere, an amount entirely negligible with respect to pressures on the high side of the diaphragm, so far as its effect in altering the weight of steam discharged is concerned.

5 The same orifice was used in all the tests. It was formed in a $\frac{1}{2}$-in. plate with edges rounded to a $\frac{1}{4}$-in. radius, the contracted diameter being 1.200 in. In figuring results, no correction was made for expansion due to the temperature of the diaphragm, owing to the smallness of the error arising from this source.

6 The amount of steam for any one test did not vary more than 5 per cent from the average amount of all the tests.

7 The results of these tests are plotted in Fig. 1, in which curve No. 1 shows the Napier coefficient corresponding to each set of the readings obtained in the various tests. Calibration tests of the orifice for saturated steam show a coefficient of about 72.3, the difference between this value and the ordinary figure of 70 being no doubt due to the form of the orifice. Taking the probable water error at 0.2 per cent, the pressure error at 0.4 per cent and the orifice error 0.1 per cent, it will be noted that the total error approximately accounts for the discrepancy in those tests that lie furthest from the average curve.

8 The formula for determining Napier's coefficient as plotted in curve No. 1 is

$$C_1 = \frac{pa}{W} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [1]$$

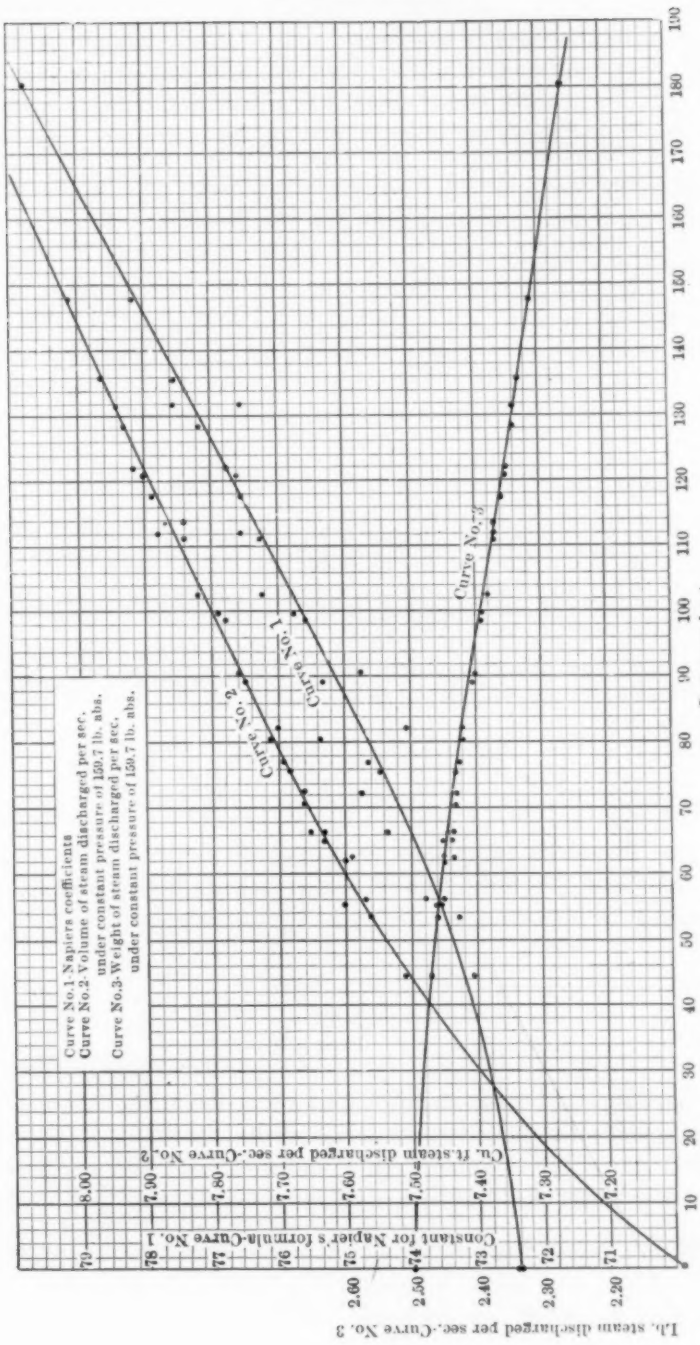
Curve No.1 Napiers coefficients
Curve No.2 Volume of steam discharged per sec. under constant pressure of 159.7 lb. abs.
Curve No.3 Weight of steam discharged per sec. under constant pressure of 159.7 lb. abs.
Curve No. 1
Curve No. 2
Curve No. 3
Deg. superheat
Constant for Napier's formula-Curve No. 1
Cu. ft. steam discharged per sec.-Curve No. 2
Lb. steam discharged per sec.-Curve No. 3

FIG. 1 RESULTS OF TESTS

where C_1 = Napier's coefficient
p = the various test pressures in lb. per sq. in. abs.
W = the weight of steam flowing per sec. in lb.
a = the area of the orifice in sq. in.

9 In curve No. 2, the cu. ft. of steam discharged per sec. is shown for different amounts of superheat, the results being reduced to the basis of the average pressure which existed in the tests in order to make the volume discharged depend on the temperature only.

10 Writing instead of p, p_1 (159.7) an arbitrary constant pressure approximating the mean pressure of the various tests, and multiplying by V_1, the specific volume of the steam at the various superheats, we have

$$W_1 V_1 = \frac{p_1 a V_1}{C_1} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [2]$$

where $W_1 V_1$ represents the volume of steam in cu. ft. per sec. which flows through the orifice for the various tests, on the assumption that the pressure was constant for all the tests. These values are plotted and form the bases of curve No. 2.

11 To solve [2] we employ the usual equation for specific volume of superheated steam, which, on substituting certain known values, becomes

$$V_1 = \frac{93.011\ T - 1097 P^{0.228}}{P} \quad \ldots\ldots\ldots\ldots\ldots\ldots [3]$$

where $P = 23{,}040$ lb. sq. in. abs. pressure, the approximate average for the tests and $T = 824.1$, the corresponding absolute temperature. A subsidiary formula used in arriving at the formula for V_1 is

$$\frac{k-1}{k} = \frac{(C_p - h)\ p}{T \frac{dp}{dt} C_p} \quad \ldots\ldots\ldots\ldots\ldots\ldots [4]$$

In this formula C_p is taken at 0.525, this being the mean value most nearly approximating the temperature-pressure conditions of the various tests. The value of h employed is that given in Professor Heck's paper on the Thermal Properties of Superheated Steam.[1] The value $\frac{dp}{dt}$ employed corresponds to the pressure and temperature as given

[1] Trans. Am. Soc. M. E., vol. 30, p. 292.

above and equals 1.9943. The pressure is of course a linear factor in Napier's coefficient with saturated steam, and even though it is not so with superheated steam, the results are interesting as indicating how far from constant the coefficient is for superheated steam for the given pressure.

12 Dividing the value given in curve No. 2 by the specific volume V_1 corresponding to the observed temperature, and the constant pressure p_1 (159.7), we have the weight of W_1 discharged, assuming that the initial pressure remains constant and equal to p_1. These values are plotted and form the bases of curve No. 3, the weight of W_1 being determined by means of the equation

$$W_1 = \frac{p_1 a}{C_1} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [5]$$

13 No quantitative results can be obtained from these data to show the effect of superheat on flow of steam in piping, but in general they seem to indicate the necessity of investigation and probable revision of the assumption frequently made that substantially smaller pipe sizes can be used for the transfer of a given amount of energy with a given pressure drop.

COMBUSTION AND BOILER EFFICIENCY

THE IMPORTANCE OF CARBON DIOXIDE AS AN INDEX TO COMBUSTION AND, IN CONNECTION WITH FLUE-GAS TEMPERATURE, TO BOILER EFFICIENCY

By Edw. A. Uehling, Passaic, N. J.

Member of the Society

It is now fully recognized by all progressive and observing engineers and managers of power houses that there is more room for economy in the boiler house than in any other part of the plant. It is therefore not due so much to lack of recognition of the fact that there is still from 5% to 25% of the available energy of the coal needlessly wasted that this waste continues to an appalling degree, as to the inherent difficulty in regulating combustion so that the loss may be reduced to a minimum.

2 A steam engine correctly designed, properly constructed, accurately adjusted and adapted to the work to be performed will give maximum economy. The attendant can do little or nothing either to increase or to decrease its efficiency. This is true also, and perhaps even to a greater degree, of the steam turbine and the dynamo. Certain definitely fixed and automatic adjustments having been found to give maximum economy, the efficiency will continue so long as these adjustments are maintained. An occasional economy test is all that is required to maintain maximum efficiency.

3 The efficiency of the steam generator depends on far more complex conditions, many of which are not only beyond control but are continually changing. Some of them are: First, *atmospheric conditions*; i.e., the barometric pressure, humidity of the atmosphere, direction and velocity of the wind, all of which affect combustion. Second, *the quality of the fuel*, which at best is never quite uniform, even when similar in kind, and often varies greatly in its con-

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tent of moisture, fixed carbon, volatile combustible matter, oxygen, ash, etc.; also its physical condition, unless specially prepared, may and often does vary from large lumps to fine powder. Third, *the condition of the boiler* as to setting, dirty heating surface, air infiltration, draft, etc. The grates become choked with slate and clinker, obstructing the air passage and causing irregular flow, resulting in a deficiency in one place and an excess in another. Every one of these variables affects the efficiency of the boiler furnace. Fourth, *the required output*, which varies in some plants between very wide limits, not infrequently from 50% overload to 50% below normal capacity in short intervals of time.

4 From the foregoing it becomes quite evident that steam-boiler economy is a complex problem, and no matter how well a boiler may be designed and how perfectly constructed, it cannot be permanently adjusted to operate with maximum efficiency under the varying conditions which obtain, even under the most favorable circumstances. Permanent adjustments of a steam boiler cannot be made, as in a steam engine, to obtain maximum efficiency.

5 The heat energy carried off by the flue gas in general boiler-room practice is rarely as low as 15% and not infrequently reaches 40% of the calorific value of the fuel burned under the boiler.

6 This loss is made up of two distinct factors, the sensible heat of the flue gas and the potential heat of the combustible constitutents it contains. The former varies directly as the stack temperature and inversely as the percentage of CO_2. The latter is independent of the stack temperature, but for any given percentage of combustible constitutents in the flue gas the loss also varies inversely as the percentage of CO_2. The only heat loss that is independent of the percentage of CO_2 in the flue gas is that due to the moisture contained in the fuel, but it is dependent on the stack temperature. The percentage of CO_2 and the stack temperature are, therefore, the two controlling factors.

7 For any given boiler and setting driven at a given rate the temperature of the flue gas depends on the condition of the heating surface and on the amount of air infiltration. When the heating surface becomes dirty, either inside or outside, or both, the stack temperature will be correspondingly higher, other conditions being the same. Air infiltration lowers the stack temperature in proportion to its ratio to the actual products of combustion. We have, therefore, two conflicting conditions that influence the stack temperature. Because of dirty heating surface, it should be above normal, but air

infiltration may actually bring it below normal, so that the stack temperature alone cannot be depended upon as an index to either economical or wasteful operation, especially since it gives no clue to the efficiency of the furnace.

8 When excessive air infiltration takes place, it becomes manifest at once by an abnormally low percentage of CO_2, so that a knowledge of the latter is necessary to understand the true significance of the former. Hence, it is evident that to produce maximum economy, or even good average results, some means should be provided to indicate to the attendant continuously what his fires are doing.

9 Provided the boiler is properly designed and set and is otherwise in proper condition, i.e., clean inside and out, its economy depends entirely on the regulation of the furnace. This again depends upon the regularity of fuel and air supply in the correct proportion and through the proper channels. Since the composition of the products of combustion gives immediate evidence of the furnace operation, it follows that in the analysis of the flue gases lies the key to the attainment of maximum efficiency, and the most progressive engineers and managers of power plants have employed gas analysis in a more or less thorough manner as a means for obtaining increased boiler-house economy.

10 Since the excess of oxygen is necessary for complete combustion, it is held by some combustion experts that O is a better index to the efficiency of combustion and boiler economy than CO_2.

11 A study of the classified tables of analyses given in Appendix No. 1, and more especially a study of the diagrams (Figs. 1 to 4) plotted from these analyses, may lead to the conclusion that the percentage of O might answer as well as the percentage of CO_2, but hardly better. When we consider that CO_2 is very much more readily determined than O, and that there are a number of practicable instruments on the market that will autographically record the percentage of CO_2 in the flue gas at short intervals, one of which will make a continuous record and at the same time indicate the percentage of CO_2 at the boiler front, there can be little room for doubt as to which of the constituents is the better adapted to serve as the index of economical combustion.

12 It may be questioned whether a knowledge of the percentage of CO_2 is sufficient for economical firing. Is it not necessary to know the percentage of oxygen (O), carbon monoxide (CO), hydrogen (H) and hydrocarbons (C_xH_y) as well?

13 For scientific tests and investigations, complete analyses of the products of combustion should always be made, and if in addition a heat balance is to be made, it is necessary to determine the weight of the coal, the volume or weight of the water, the qualtiy of the steam as to entrained moisture and superheat, and the weight of ash and the unconsumed carbon it contains. It is evident that such tests can only be carried on by an expert with the necessary scientific apparatus and the help of competent assistants. They are, therefore, not available for every-day practice. Occasional tests are undoubtedly of great value, especially for the purpose of determining the most economical percentage of CO_2 for the kind of fuel used and the conditions prevailing, but what is needed is a continuously available index. For such index the choice can lie only between CO_2 and O and, for reasons already given, CO_2 is much to be preferred.

14 The tables of analyses and the graphic illlustrations show conclusively that under normal conditions of combustion there is a very definite relation between the percentage of CO_2 and O contained in the flue gas. The percentage of O falls almost exactly in the same ratio as CO_2 goes up and vice versa. The analyses also show conclusively that there is no relation between either O or CO_2 and CO. High O and low CO_2 is no guarantee that CO may not be present, nor does it follow that high CO_2 and low O means incomplete combustion. All that we can discern with certainty is that there is a tendency toward higher CO as the percentage of CO_2 goes up. This tendency increases very moderately at the lower range of CO_2 but more and more rapidly as the maximum percentage of CO_2 is reached. Since the ratio of carbon burned to CO to that burned to CO_2 equals $\frac{P_c}{P + P_c}$ (see Par. 51), it follows that the loss (L_c) due to carbon monoxide for the same percentage of CO varies inversely as the percentage of CO_2, e.g., 1% of CO in flue gas containing 5% of CO_2 causes as great a loss as 3% CO associated with 15% of CO_2. The same holds true of the loss due to all the combustion products with the exception of the moisture contained in the fuel. The general conclusion that the chimney heat loss varies inversely as the percentage of the CO_2 in flue gas seems, therefore, warranted. Modifying influences are considered in Pars. 22 to 26.

15 The tables in Appendix No. 1 constitute 1130 flue-gas analyses from various sources, representing many kinds of fuel and furnace conditions. These analyses were classified in Tables 1, 3, 5, 7 and 9 with reference to the percentage of CO_2 and in Tables 2, 4, 6, 8

and 10 with reference to the percentage of O. For the benefit of those who kindly furnished a large number of these analyses, they were further classified according to source and some of these again with reference to totals obtained by adding together the three oxygen components, viz., CO_2, O and CO.

16 The right-hand column of each table gives the total of the components determined and it will be noticed that these totals vary considerably. In the Government analyses (Tables 1 and 2) they vary from 16.7% to 20.8%, i.e., fully 4.1% of the total gas or 20% from one another. There is, however, only one instance below 17% and only four below 18%, 20 between 18% and 19%, 287 between 19% and 20%, and 277 between 20% and 20.8%, which is the highest total found.

17 The sum of the percentages of CO_2, O and CO contained in flue gas varies with the excess of air, the degree of completeness of combustion, the composition of the fuel and the temperature at which the gas is analyzed. When combustion is complete and the fuel consists of carbon only, the sum of CO_2 and O cannot exceed the percentage of oxygen in the air, viz: 21% (see Par. 47). It will always be less than this, because the gas is saturated with moisture, which in general gas analyses is reckoned with the nitrogen. This introduces a possible difference of 1.3% due to the differences in the moisture content of the gas between 62 deg. and 92 deg., a range of 30 deg.

18 *Incomplete Combustion.* When carbon is burned to CO every molecule of O_2 combines with two atoms of carbon and forms two molecules of CO. The gas may, therefore, contain 34.7% of CO as a maximum. Therefore, if combustion is incomplete and CO is present, the sum of $CO_2 + O_2 + CO$ in dry gas may be greater than 21% by an amount equal to $\frac{34.7-21}{34.7} \times CO = 0.4\,CO$, so that in this case the sum of the oxygen components in saturated gas would be $21 + 0.4\,CO - \frac{H_2O \times 21}{100}$. Since the percentage of CO in normal flue gas reaches 1% only in exceptional cases and the reduction due to moisture is not likely to be less than 1%, flue-gas analyses in which the sum of the oxygen components exceeds 21% must be looked on with suspicion.

19 In burning fuel containing any considerable quantity of hydrogen the sum of CO_2+O_2+CO will always be less than 21% in

normal flue gas, because all the oxygen which combines with the H_2 forms water vapor, which is condensed, while the nitrogen remains as a diluent. Carbon and hydrogen require respectively 152 and 457 cu. ft. of air for complete combustion (see Par. 47 and 55). The products of combustion are composed of 31.92 cu. ft. of CO_2 and 120.08 cu. ft. of nitrogen for carbon and 361 cu. ft. of nitrogen for hydrogen. When burning fuel containing a high ratio of available hydrogen to carbon, Illinois bituminous coal for example, in which $\frac{H_a}{C} = 0.06$, assuming complete combustion with the theoretically required volume of air, then $\frac{152 \times 21}{152+(361 \times 0.06)} = 18.4\%$ is the maximum CO_2 obtainable from this coal. If the above coal is burned with 50% excess of air, again assuming complete combustion, the flue gas would be composed of $\frac{152 \times 21}{228 + 32.5} = 12.25\%$ CO_2 and $\frac{86.8 \times 21}{228 + 32.5} = 7\%$ O, or a total of 19.25%. Now if we assume the gas to contain 0.5% CO, the sum of $CO_2+O_2+CO = 12.25 +7+0.4\times0.5=19.45\%$. If the gas were analyzed at a temperature of 92 deg. the result would be 9.6% less than the above, due to moisture in the gas. The analytical result would therefore be 17.58%.

20 This is an extreme case, but it shows that large variations may legitimately occur in the sum of the oxygen components contained in combustion products. It also shows that the temperature at which gas analyses are made should be taken into consideration. It brings out the further fact that the maximum percentage of CO_2 that may be contained in flue gas decreases as the ratio of carbon to hydogen in the coal increases, from which it becomes evident that the most economical percentage of CO_2 must vary with the kind of fuel. It will be several per cent higher with anthracite than with bituminous coal, and varies in the latter with the ratio of carbon to available hydrogen.

21 The highest practicable furnace efficiency obtains when the greatest possible part of the potential energy contained in the coal is converted into sensible heat by combustion. The highest boiler efficiency results when a minimum of this heat is carried off by the flue gas. The former is realized when combustion is complete, the

latter when the weight and temperature of the flue gas are a minimum. Since the weight of flue gas decreases as the percentage of CO_2 increases, high boiler efficiency requires high CO_2.

22 On the other hand, when the furnace is run so as to produce a maximum percentage of CO_2 there is danger of reducing its efficiency because of incomplete combustion due to a minimum of free oxygen. It would seem, therefore, that the highest combined efficiency of boiler and furnace would be obtained when the gain due to reduced weight of flue gas, i.e., due to an increased percentage of CO_2 is balanced by the loss due to incomplete combustion.

23 The most economical percentage of CO_2 varies theoretically with the ratio of available hydrogen to carbon $\left(\frac{H_a}{C}\right)$, but in practice it is influenced by many modifying conditions. In every case, however, there is a percentage of CO_2 which gives best results. Its value as an index, therefore, is not dependent on the kind of fuel used or the local conditions existing.

24 Next to careless or unskillful firing, air infiltration causes the greatest loss in the flue gas. Unless especially provided against, it is rarely less than 15 to 20% of the volume of the flue gas and not infrequently reaches 50% and over when cracks in the settings are allowed to exist and warped and badly fitting cleaning doors are tolerated. Professor Breckenridge, in his discussion of the boiler tests carried on by the Government under his direction at St. Louis, estimates the air infiltration at from 25 to 30%, and it would be presumptuous to assume that the boilers used for these tests were not in at least as good condition as those in the average power plant.

25 Comparing Tables 1 and 2 with Tables 5 and 6 it will be noticed that the percentage of CO_2 is much lower in the former than in the latter set of analyses and, what is even more striking, that CO occurs with greater frequency and in larger amount in the Government tests than in those represented in Tables 5 and 6. It would seem proper to infer that this is due, largely at least, to much greater air infiltration in the former case than in the latter and that at least 20% should be added to the CO_2 and CO, and subtracted from the O in order to represent correctly the composition of the combustion products formed in the furnace. From Tables 5 and 6 it is apparent that a high percentage of CO_2 is possible without undue loss of combustible in the flue gas.

26 Tables 7 and 8 are peculiar in that the sum of the oxygen components is below 19%. Compared with Tables 5 and 6 oxygen

is low, and the CO is rarely absent and comparatively very high. Unfortunately there are no data upon which to base an explanation. It is probable, however, the analyses in Tables 7 and 8 were made at a higher temperature than those in Tables 1, 2, 3 and 4. It is also possible that the oxygen may not have been fully absorbed, but this is mere conjecture. The high percentage of CO, even in connection with a comparatively moderate percentage of CO_2, points to injudicious firing. There are good reasons, however, to suspect that there is something wrong with these analyses and part of those in Tables 9 and 10. These reasons are given in Par. 32.

27 Tables 3 and 4 show a set of analyses which were obtained from tests of a locomotive under widely varying conditions of forced draft, which ranged from 0.59 in. to 11.8 in. of water, the corresponding rates of driving varying from 19.2 lb. to 114.6 lb. of coal burned per sq. ft. of grate surface per hr. The analyses are unique, because of the facts just mentioned and because conditions absolutely preclude air infiltration. The oxygen components in this set of analyses vary less than 1%, which is as it should be, the coal used being similar in kinds in all the tests. The comparatively low and uniform percentage of CO is remarkable considering the extreme variation in the rate of driving.

28 The lowest percentage of CO in these tests occurs with an excess of 6.92% O and the highest 0.3 % CO with an excess of 6.74% O. The average excess of O in the upper seven analyses is 7.5% in the lower seven analyses it is 6.1%, a difference of 1.4%, yet the average percentage of CO is almostly the same, viz., 0.17%. The respective average percentages of CO_2 are 11.33 and 12.91, a difference of 1.58%. This corroborates the statement previously made that within moderate limits the percentage of CO does not vary either with the percentage of O or with the percentage of CO_2 contained in the flue gas. So far as these analyses indicate, it is also independent of the rate of driving.

29 Tables 5 and 6 are peculiar in that they contain no analysis in which the sum of the oxygen component is less than 19%. This set of analyses is remarkable because CO was found in only ten of the 167 six-hour samples represented, and only two of these contained as high as 0.4% of this constituent, accompanied respectively by 9.9% of CO_2 and 8.9% of O, and 12% of CO_2 and 6.6% of O. It is not until the CO_2 exceeds 10% and the O falls below 6% that CO appears with some frequency. Taking the last seven analyses of Table 6 we find an average of 13.4% CO_2 and 0.1% CO.

30 We have shown in Par. 19 that when burning coal in which $\frac{H_a}{C} = 0.06$ with 50% excess of air the flue gas should contain 12.25% CO_2 and 7% O. It would, therefore, seem reasonable to conclude that when burning coal in which the ratio $\frac{H_a}{C}$ does not exceed 0.05, if the CO exceeds 0.2% or at most 0.3% in flue gas containing 12% to 14% of CO_2 and 7% to 5% of O there is something wrong with the method of firing, the furnace, the construction, the setting or all of them.

31 In Pars. 17 to 20 an attempt is made to show why the sum of the oxygen components contained in flue gas does vary and to what extent it may vary legitimately. It was shown that a considerable variation may be due to a variation in the temperature at which the gas is analyzed, that the presence of CO augments the sum of the oxygen components by 0.4 of its value, and that the presence of H_2 in the fuel reduces this sum very materially. It follows, then, that for similar fuel the higher percentage of CO should coincide with the higher sum of the oxygen components.

32 In the tables the analyses in which the sum of the oxygen components is less than 19% are marked with a star, and all those in which the CO exceeds 0.3% are marked with a cross. Examining Table 1, we find that 69 out of the 609 analyses show CO above 0.3%, and in only five of these is the sum of the oxygen components less than 19%. In Table 9 we find that in a total of 126 samples, 36 contain over 0.3% of CO, every one of which occurs with oxygen components summing up to less than 19%. Table 7 shows the same discrepancy. Out of the 224 analyses there tabulated, 67 show CO above 0.4%, for all of which the oxygen components are below the average. So far as we know, the coal burned did not vary greatly, certainly not nearly so much as in the Government tests. We feel justified, therefore, in doubting the correctness of the analyses given in Tables 7 and 8 and no weight should be attached to them in drawing conclusions. We think it none the less proper to include them in this paper with our reason for doubting their correctness.

DIAGRAMATIC REPRESENTATION OF ANALYSES

33 The averages varying by 0.1% of Tables 1, 2, 3 and 4 are plotted in Fig. 1, those of Tables 5 and 6 in Fig. 2, and those of

Tables 7 and 8 ,and 9 and 10 respectively in Figs. 3 and 4. The straight lines represent the theoretical amounts of CO_2 and O which the combustion products would contain if pure carbon were burned with pure air. The analyses were plotted with regard to the percentage of CO_2 and O respectively. The CO_2 was placed in its proper position on the theoretical CO_2 line for the percentages of CO_2 and then the accompanying percentages of O and CO were plotted on the same ordinate in the position called for by their value. In the same manner the O was placed on the theoretical oxygen line and the CO_2 and CO were plotted according to their values on the same ordinate. To show the values of CO more clearly, they are multiplied by five.

34 Fig. 1 shows that the percentage of O diminishes as the CO_2 increases, and vice versa, the percentage of CO_2 increases as the O becomes less. It will be noted that both the O and CO_2 lines converge toward the theoretical line as the CO_2 diminishes, which is as it should be if the analyses are correct, because when the CO_2 is zero, the percent of O must be that of the air, viz., 21%. The amount of divergence from the theoretical line towards zero O depends on the value of $\frac{H_2}{C}$ in the fuel.

35 Considering the great variety of fuels represented by the Government analyses it is remarkable with what uniformity the CO_2 and O vary in accordance with what should be expected from theoretical considerations. This becomes even more remarkable when we observe how harmoniously the analyses of Tables 3 and 4 (represented by the somewhat heavier lines) fit in with those of Tables 1 and 2, especially when we consider that the latter were derived from entirely different test conditions. From this we may be justified in concluding that the relation of CO_2 to O shown in Fig. 1 holds true for all ordinary conditions of simple combustion. It therefore follows that if we know the percentage of CO_2 contained in the products of combustion we may infer from it with a practical degree of approximation the accompanying percentage of O, and vice versa.

36 That no such reliable relation exists between the CO and either of the former has already been stated. That this should be so becomes quite evident when we consider that the relation between CO_2 and O depends on a natural law, whereas the percentage of CO in a large degree depends on caprice. In Table 2 we find 0.5% CO with 13.6% of O and in Table 6 we find analyses which show complete combustion with less than 6% of O. It is evident, therefore,

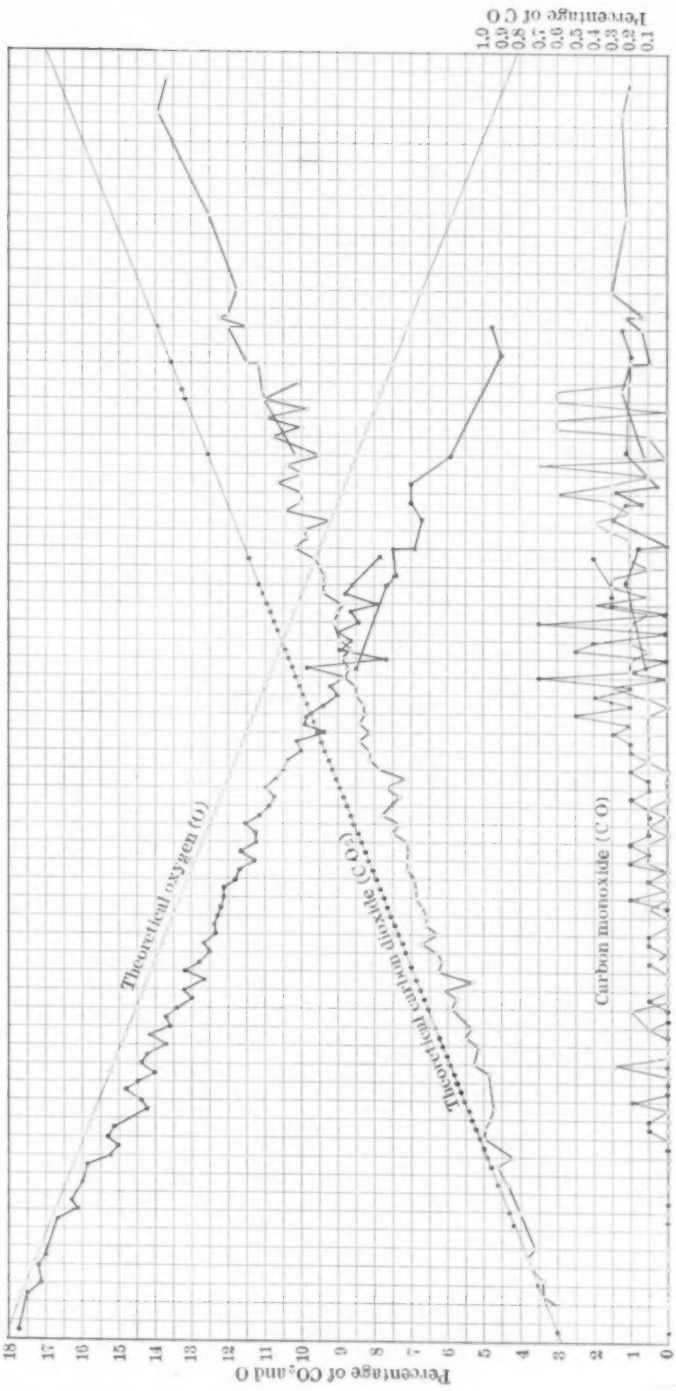

FIG. 1 DIAGRAMATIC REPRESENTATION OF ANALYSES GIVEN IN TABLES 1, 2, 3 AND 4

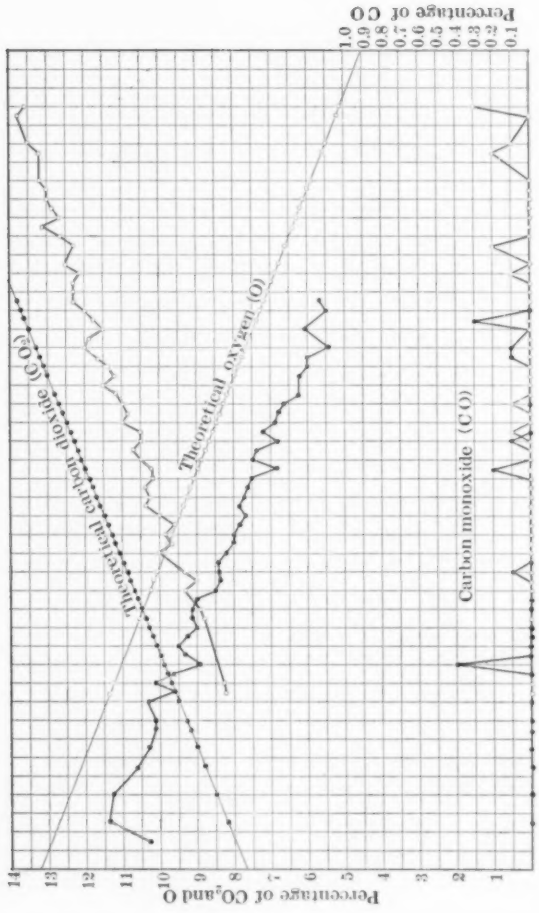

FIG. 2 DIAGRAMATIC REPRESENTATION OF ANALYSES GIVEN IN TABLES 5 AND 6

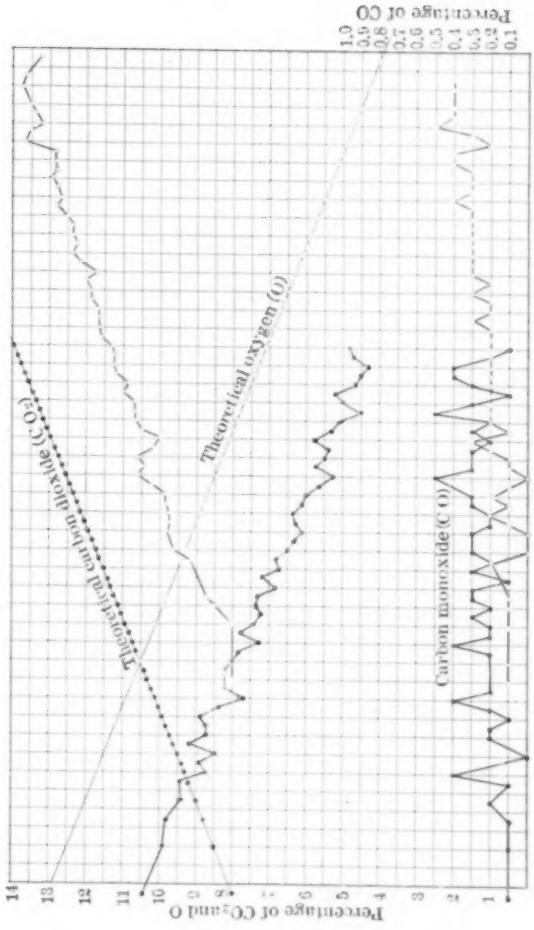

FIG. 3 DIAGRAMATIC REPRESENTATION OF ANALYSES GIVEN IN TABLES 7 AND 8

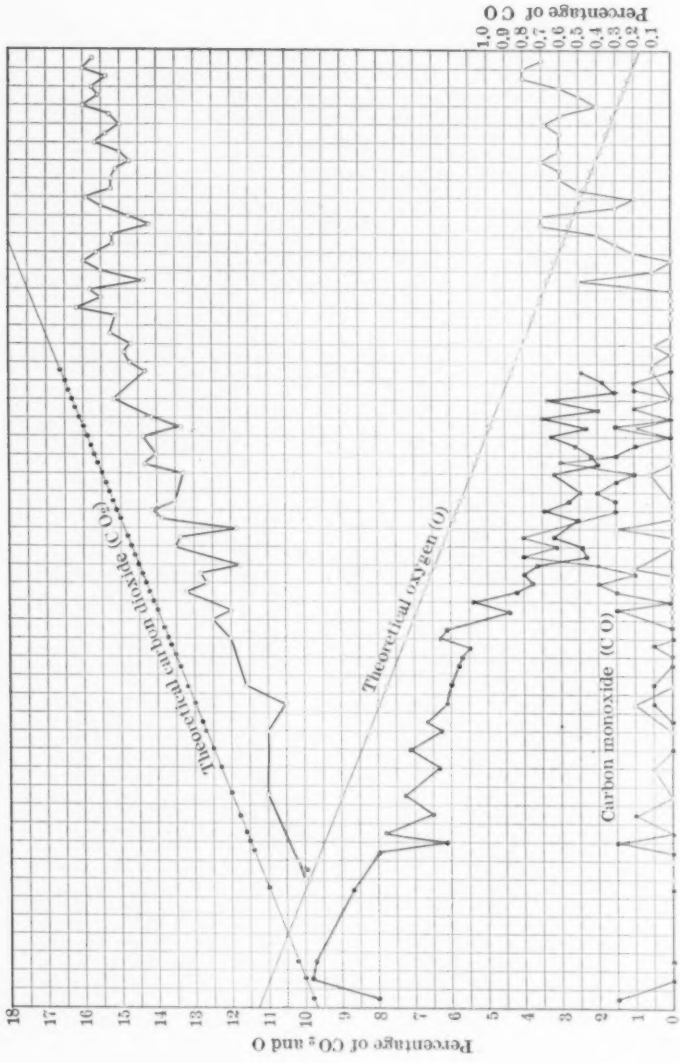

FIG. 4 DIAGRAMATIC REPRESENTATION OF ANALYSES GIVEN IN TABLES 9 AND 10

that 6% of O is sufficient when the conditions are right and that a large percentage of O will not insure complete combustion when the conditions are bad.

37 The CO line in Fig. 1 illustrates the irregularity of this component. It was stated at the outset that the tendency toward a higher percentage of CO in flue gas becomes increasingly greater as the percentage of CO_2 goes up; but the diagram shows a maximum of over 0.4% of CO with CO_2 between 10% and 11%, whereas with CO_2 between 11% and 14% the CO does not average above 0.2%. This apparent anomaly is explained by the fact that Government analyses include from 20 to 30% of infiltrated air and that the real combustion products contained about 25% more CO_2 and 25% less O than the analyses show. In reality, therefore, the high CO readings occurred with CO_2 from 12.5 to 13.75%. This would place the high CO in its proper relation to CO_2, but the contrast as compared with the CO found in the flue gas of the locomotive test still remains and is evidence of uneconomical firing.

38 Passing to Fig. 2 we notice the same characteristics as in Fig. 1, viz., the O line follows a trend which should meet the theoretical O line at 21% when CO_2 reaches zero, and the CO_2 follows a trend which would meet the zero point of the theoretical CO_2 line when O reaches 21%. The CO is irregular and has a moderate tendency towards higher values as the CO_2 reaches the higher values. With the exception of the few analyses previously discussed, this diagram shows very good combustion.

39 Fig. 3 corroborates what has already been said about the analyses from which it was plotted. The CO line is irregular and high, and only slightly higher with CO_2 above 11% than below. Both the CO_2 and the O line show that the analyses are deficient in the O components, nor does the trend of the O line converge toward the theoretical line as it should. The correctness of the analyses in Tables 7 and 8 must, therefore, stand questioned, and other than showing this fact, little value can be attached to the diagrams in Fig. 3.

40 The suspicion as to the correctness of the analyses in Tables 9 and 10 is strengthened to an even greater extent by study of Fig. 4. The analyses appear to be particularly faulty with the higher CO_2 and the correspondingly lower O content. The high and erratic CO line shows that the firing must have been irregular and bad. But reliable conclusions cannot be drawn from this diagram except that at least a large number of the analyses cannot be considered reliable.

CALCULATION OF HEAT CARRIED OFF BY THE FLUE GAS

41 In Appendix No. 2 an attempt has been made to formulate simple equations by which the heat and heat energy carried off by the flue gas can readily be calculated for all kinds of fuel, provided we have a correct analysis of the fuel burned and the flue gas produced.

CONCLUSIONS

42 We must conclude from these calculations that the percentage of CO_2 and the stack temperature are the two controlling factors in the production of furnace and boiler efficiency. In view of the fact that both of these components are so easily determined and that apparatus is in existence which will continuously indicate and record them, it is lamentable that more general use is not made of these indexes.

43 There is today no valid reason why scientific methods should not prevail in securing fuel, as well as in consuming it, especially for power purposes, nor is there any reason why consumers of large quantities of coal should be ignorant of its ultimate, as well as its proximate composition.

44 It is not generally feasible, nor is it at all necessary, in order to obtain the most economical results, that calculations be based on the ultimate analysis of the coal, but a full analysis of the flue gas should form part of the daily routine. Inasmuch, however, as the most economical percentage of CO_2 varies considerably with the kind of fuel used, and also to some extent on the method of firing, hand or mechanical, the kind of stoker and rate of driving, it becomes very desirable, if not absolutely necessary, to make a series of tests in which all the essential elements are determined.

45 Having established the most economical value of CO_2, this component of the flue gas will serve as a correct guide to the fireman. An automatic record, preferably a continuous one, for the engineer is of the greatest value. If, in addition, the stack temperature is indicated for the fireman and recorded for the engineer in charge there should be little difficulty in getting maximum efficiency.

APPENDIX NO. 1

GAS ANALYSES FROM VARIOUS SOURCES

U. S. Government Tests[1]

TABLE 1

Arranged According to CO_2

	CO_2	O	CO	Total
	2.0	18.4	0	20.4
	3.0	17.7	0	20.7
	3.4	17.5	0	20.9
	3.4	17.6	0	21.0
Aver.	3.4	17.5	0	
	3.5	17.1	0	20.6
	3.7	17.3	0	21.0
	3.7	17.1	0	20.8
Aver.	3.7	17.2	0	
	3.8	16.7	0	20.5
	3.8	17.2	0	21.0
Aver.	3.8	17.0	0	
	4.0	16.1	0	20.1
	4.2	16.7	0	20.9
	4.3	16.1	0	20.4
	4.4	16.1	0	20.5
	4.4	16.4	0	20.8
Aver.	4.4	16.3	0	
	4.6	16.2	0	20.8
	4.6	15.7	0	20.3
Aver.	4.6	16.0	0	
	4.8	16.2	0	21.0
	4.8	15.8	0	20.6
	4.8	15.6	0	20.4
Aver.	4.8	15.9	0	

TABLE 2

Arranged According to O

	O	CO_2	CO	Total
	18.4	2.0	0	20.4
	17.7	3.0	0	20.7
	17.6	3.4	0	21.0
	17.5	3.4	0	20.9
	17.3	3.7	0	21.0
	17.2	3.8	0	21.0
	17.1	3.5	0	20.6
	17.1	3.7	0	20.8
Aver.	17.1	3.6	0	
	16.7	4.2	0	20.9
	16.7	3.8	0	20.5
Aver.	16.7	4.0	0	
	16.4	4.4	0	20.8
	16.2	4.6	0	20.8
	16.1	4.0	0	20.1
	16.1	4.3	0	20.4
	16.1	4.4	0	20.5
Aver.	16.1	4.2	0	
	15.9	5.0	0	20.9
	15.8	4.8	0	20.6
	15.8	5.2	0	21.0
Aver.	15.8	5.0	0	

[1]Coal Testing Station, Louisiana Purchase Exposition, U. S. Geological Survey Report, Part 2, Boiler Tests.

U. S. Government Tests

TABLE 1—Continued

ARRANGED ACCORDING TO CO_2

	CO_2	O	CO	Total
	4.9	15.2	0	20.1
	5.0	14.7	0.1	19.8
	5.0	15.9	0	20.9
	5.0	15.0	0	20.0
	5.0	14.4	0	19.4
Aver.	5.0	15.0	0	
	5.1	15.7	0	20.8
	5.1	14.9	0	20.0
Aver.	5.1	15.3	0	
	5.2	15.8	0	21.0
	5.2	14.7	0.2	20.1
	5.2	14.8	0	20.0
Aver.	5.2	15.1	0.1	
	5.3	15.1	0.3	20.7
	5.3	14.8	0.1	20.2
	5.3	14.9	0	20.2
	5.3	13.9	0	19.2
	5.3	14.7	0	20.0
Aver.	5.3	14.7	0.1	
	5.4	14.2	0	19.6
	5.5	14.4	0.2	20.1
	5.6	14.8	0	20.4
	5.6	15.0	0	20.6
	5.6	14.5	0	20.1
Aver.	5.6	14.8	0	
	5.7	14.4	0	20.1
	5.7	14.5	0	20.2
Aver.	5.7	14.5	0	
	5.8	13.4	0.3	19.5
	5.8	12.7	0	18.5
	5.8	14.7	0	20.5
	5.8	14.8	0	20.6
	5.8	14.3	0	20.1
Aver	5.8	14.0	0	
	5.9	14.5	0	20.4
	5.9	14.1	0	20.0
	5.9	14.7	0	20.6
	5.9	14.0	0	19.9
	5.9	14.5	0.2	20.6
Aver.	5.9	14.4	0	20.3

TABLE 2—Continued

ARRANGED ACCORDING TO O

	O	CO_2	CO	Total
	15.7	5.1	0	20.8
	15.7	4.6	0	20.3
Aver.	15.7	4.9	0	
	15.6	4.8	0	20.4
	15.2	4.9	0	20.1
	15.1	5.3	0.3	20.7
	15.0	5.0	0	20.0
	15.0	5.6	0	20.6
Aver.	15.0	5.3	0	
	14.9	5.3	0	20.2
	14.9	5.1	0	20.0
Aver.	14.9	5.2	0	
	14.8	5.2	0	20.0
	14.8	5.3	0.1	20.2
	14.8	5.8	0	20.6
	14.8	5.6	0	20.4
Aver.	14.8	5.5	0	
	14.7	5.9	0	20.6
	14.7	5.8	0	20.5
	14.7	5.3	0	20.0
	14.7	5.2	0.2	20.1
	14.7	5.0	0.1	19.8
Aver.	14.7	5.4	0.1	
	14.5	6.2	0.2	20.9
	14.5	6.2	0	20.7
	14.5	6.0	0	20.5
	14.5	5.9	0.2	20.6
	14.5	5.9	0	20.4
	14.5	5.7	0	20.2
	14.5	5.6	0	20.1
Aver.	14.5	5.9	0.1	
	14.4	5.0	0	19.4
	14.4	6.2	0	20.6
	14.4	6.0	0	20.4
	14.4	6.0	0	20.4
	14.4	6.0	0	20.4
	14.4	6.0	0	20.4
	14.4	5.7	0	20.1
	14.4	5.5	0.2	20.1
Aver.	14.4	5.8	0	

U. S. Government Tests

TABLE 1—Continued

ARRANGED ACCORDING TO CO_2

CO_2	O	CO	Total
6.0	14.4	0	20.4
6.0	14.4	0	20.4
6.0	14.5	0	20.5
6.0	13.6	0	19.6
6.0	14.0	0	20.0
6.0	14.4	0	20.4
6.0	14.4	0	20.4
Aver.....6.0	14.2	0	
6.1	13.7	0	19.8
6.1	13.6	0	19.7
6.1	13.7	0	19.8
Aver.....6.1	13.7	0	
6.2	14.4	0	20.6
6.2	14.5	0	20.7
6.2	14.1	0	20.3
6.2	14.5	0.2	20.9
6.2	13.7	0	19.9
6.2	13.2	0	19.4
Aver.....6.2	14.1	0	
6.3	13.1	0	19.4
†6.3	12.7	0.4	19.4
6.3	14.3	0	20.6
6.3	14.3	0	20.6
6.3	13.7	0	20.0
Aver..... 6.3	13.6	0.1	
6.4	13.4	0	19.8
6.4	13.8	0	20.2
†6.4	13.6	0.5	20.5
6.4	13.7	0	20.1
6.4	14.0	0	20.4
6.4	13.4	0	19.8
6.4	13.6	0	20.0
6.4	13.6	0	20.0
6.4	14.0	0	20.4
Aver..... 6.4	13.7	0	
6.5	14.2	0	20.7
6.5	12.9	0.3	19.7
6.5	13.0	0	19.5
6.5	13.1	0.1	19.7
6.5	13.5	0	20.0
6.5	13.8	0	20.3
Aver..... 6.5	13.4	0	
6.6	13.3	0.3	20.2
6.6	13.5	0	20.1
6.6	13.6	0	20.2

Continued on next page

TABLE 2—Continued

ARRANGED ACCORDING TO O

O	CO	CO	Total
14.3	5.8	0	20.1
14.3	6.3	0	20.6
14.3	6.3	0	20.6
Aver.....14.3	6.1	0	
14.2	5.4	0	19.6
14.1	5.9	0	20.0
14.1	6.2	0	20.3
14.1	6.7	0	20.8
Aver.....14.1	6.3	0	
14.0	6.4	0	20.4
14.0	6.4	0	20.4
14.0	6.0	0	20.0
14.0	5.9	0	19.9
Aver.....14.0	6.2	0	
13.9	6.7	0	20.6
13.9	6.9	0.1	20.9
13.9	5.3	0	19.2
Aver.....13.9	6.3	0	
13.8	7.2	0	21.0
13.8	6.8	0	20.6
13.8	6.5	0	20.3
13.8	6.4	0	20.2
Aver.....13.8	6.7	0	
13.7	6.1	0	19.8
13.7	6.1	0	19.8
13.7	6.2	0	19.9
13.7	6.3	0	20.0
13.7	6.7	0	20.4
13.7	6.4	0	20.1
Aver..... 13.7	6.3	0	
13.6	7.4	0	21.0
13.6	6.8	0	20.4
13.6	6.8	0	20.4
13.6	6.7	0	20.3
13.6	6.6	0.5	20.5
13.6	6.6	0	20.2
13.6	6.4	0	20.0
13.6	6.4	0	20.0
13.6	7.1	0	20.7
13.6	6.1	0	19.7
13.6	6.0	0	19.6
Aver.....13.6	6.6	0	
13.5	6.6	0	20.1
13.5	6.5	0	20.0
Aver.....13.5	6.6	0	

U. S. Government Tests

TABLE 1—Continued

Arranged According to CO_2

	CO_2	O	CO	Total
		Continued		
	6.6	12.6	0	19.2
	6.6	13.3	0	19.9
	6.6	13.0	0.1	19.7
	6.6	12.5	0	19.1
	*6.6	12.2	0	18.8
	†6.6	12.7	0.5	19.8
	6.6	13.4	0.2	20.2
	6.6	13.6	0.3	20.5
	6.6	12.8	0	19.4
	*6.6	11.2	0	17.8
	6.6	13.0	0	19.6
	6.6	12.8	0	19.4
	6.6	13.9	0	20.5
Aver.....	6.6	13.0	0.1	
	6.7	12.9	0	19.6
	6.7	13.9	0	20.6
	6.7	12.8	0	19.5
	6.7	12.8	0	19.5
	6.7	12.9	0	19.6
	*6.7	11.5	0	18.2
	6.7	13.4	0	20.1
	6.7	13.4	0	20.1
	6.7	13.7	0	20.4
	6.7	13.6	0	20.3
	6.7	14.1	0	20.8
Aver.....	6.7	13.2	0	
	6.8	13.2	0	20.0
	6.8	13.7	0	20.4
	*6.8	11.2	0	18.0
	*6.8	10.6	0	17.4
	6.8	13.2	0	20.0
	*6.8	11.1	0.1	18.0
	6.8	13.0	0	19.8
	6.8	13.8	0	20.6
	6.8	13.6	0	20.4
Aver.....	6.8	12.6	0	
	6.9	13.3	0	20.2
	6.9	12.2	0	19.1
	6.9	13.9	0.1	20.9
	6.9	13.3	0	20.2
	6.9	13.1	0	20.0
	6.9	13.3	0	20.2
	6.9	13.3	0	20.2
	6.9	13.3	0	20.2
	6.9	12.7	0	19.6
Aver.....	6.9	13.2	0	

TABLE 2—Continued

Arranged According to O

	O	CO_2	CO	Total
	13.4	6.4	0	19.8
	13.4	6.4	0	19.8
	13.4	6.7	0	20.1
	13.4	6.7	0	20.1
	13.4	7.0	0.4	20.8
	13.4	7.2	0.3	20.9
	13.4	6.6	0.2	20.2
Aver.....	13.4	6.7	0.1	
	13.3	7.1	0	20.4
	13.3	7.0	0	20.3
	13.3	6.9	0	20.2
	13.3	6.9	0	20.2
	13.3	6.9	0	20.2
	13.3	6.9	0	20.2
	13.3	6.9	0	20.2
	13.3	6.6	0	19.9
	13.3	6.6	0.3	20.2
Aver.....	13.3	6.9	0	
	13.2	7.4	0	20.6
	13.2	6.8	0	20.0
	13.2	6.8	0	20.0
	13.2	7.2	0	20.4
	13.2	7.2	0	20.4
	13.2	6.2	0	19.4
Aver.....	13.2	6.9	0	
	13.1	6.3	0	19.4
	13.1	7.1	0	20.2
	13.1	7.0	0	20.1
	13.1	7.0	0	20.1
	13.1	6.9	0	20.0
	13.1	6.5	0.1	19.7
	13.1	7.2	0	20.3
Aver.....	13.1	6.9	0	
	13.0	7.2	0	20.2
	13.0	7.2	0	20.2
	13.0	7.8	0	20.8
	13.0	7.8	0	20.8
	13.0	6.8	0	19.8
	13.0	6.6	0	19.6
	13.0	6.5	0	19.5
	13.0	7.0	0	20.0
	13.0	7.0	0	20.0
	13.0	7.0	0	20.0
	13.0	7.0	0.1	20.1
	13.0	6.6	0.1	19.7
	13.0	7.3	0	20.3
Aver.....	13.0	7.1	0	

U. S. Government Tests

TABLE 1—Continued

Arranged According to CO_2

	CO_2	O	CO	Total
	7.0	12.6	0.1	19.7
	7.0	13.0	0	20.0
	7.0	12.4	0	19.4
	7.0	12.8	0	19.8
	7.0	13.1	0	20.1
	7.0	13.3	0	20.3
	7.0	12.2	0	19.2
	†7.0	13.4	0.4	20.8
	7.0	13.0	0	20.0
	7.0	13.0	0	20.0
	7.0	12.9	0.2	20.1
	7.0	11.9	0.1	19.0
	7.0	13.0	0.1	20.1
	7.0	13.1	0	20.1
Aver.....	7.0	12.8	0.1	
	7.1	12.2	0	19.3
	7.1	12.9	0	20.0
	7.1	12.7	0	19.8
	*7.1	9.2	0.3	16.6
	7.1	12.8	0.1	20.0
	7.1	12.4	0	19.5
	7.1	13.1	0	20.2
	7.1	13.3	0	20.4
	7.1	13.6	0	20.7
	7.1	12.7	0	19.8
.....	7.1	12.5	0	
	7.2	12.2	0	19.4
	7.2	13.4	0.3	20.9
	*7.2	10.6	0	17.8
	7.2	13.2	0	20.4
	7.2	13.2	0	20.4
	7.2	11.9	0	19.1
	7.2	13.8	0	21.0
	7.2	12.7	0	19.9
	7.2	12.5	0	19.7
	7.2	12.1	0	19.3
	7.2	12.8	0	20.0
	7.2	12.8	0.6	20.6
	7.2	12.5	0.6	20.3
	7.2	12.0	0	19.2
	7.2	12.8	0	20.0
	7.2	13.0	0	20.2
	7.2	13.1	0	20.3
	7.2	12.6	0	19.8
	7.2	13.0	0	20.2
	7.2	12.5	0	19.7
Aver.....	7.2	12.6	0.1	

TABLE 2—Continued

Arranged According to O

	O	CO	CO	Total
	12.9	7.0	0.2	20.1
	12.9	6.7	0	19.6
	12.9	6.7	0	19.6
	12.9	6.5	0.3	19.7
	12.9	7.6	0	20.5
	12.9	7.6	0	20.5
	12.9	7.3	0.2	20.4
Aver.....	12.9	7.1	0.1	
	12.8	7.2	0	20.0
	12.8	7.3	0	20.1
	12.8	7.4	0	20.2
	12.8	7.6	0	20.4
	12.8	7.6	0	20.4
	12.8	6.7	0	19.5
	12.8	6.7	0	19.5
	12.8	6.6	0	19.4
	12.8	7.2	0	20.0
	12.8	7.2	0.6	20.6
	12.8	7.1	0.1	20.0
	12.8	7.0	0	19.8
	12.8	6.6	0	19.4
Aver.....	12.8	7.1	0.1	
	12.7	6.9	0	19.6
	12.7	7.1	0	19.8
	12.7	7.1	0	19.8
	12.7	7.2	0	19.9
	12.7	6.3	0.4	19.4
	12.7	5.8	0	18.5
	12.7	6.6	0.5	19.8
	12.7	7.6	0.3	20.6
	12.7	7.6	0	20.3
	12.7	7.4	0.1	20.2
	12.7	7.4	0	20.1
	12.7	7.3	0	20.0
	12.7	7.3	0	20.0
	12.7	7.3	0	20.0
Aver	12.7	7.1	0.1	
	12.6	7.2	0	19.8
	12.6	7.4	0	20.0
	12.6	7.4	0	20.0
	12.6	7.4	0	20.0
	12.6	7.5	0	20.1
	12.6	7.5	0	20.1
	12.6	7.8	0	20.4
	12.6	7.8	0	20.4

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U. S. Government Tests

TABLE 1—Continued

ARRANGED ACCORDING TO CO_2

	CO_2	O	CO	Total
	7.3	13.0	0	20.3
	7.3	12.7	0	20.0
	7.3	12.2	0	19.5
	7.3	12.9	0.2	20.4
	7.3	11.9	0	19.2
	†7.3	12.3	0.5	20.1
	†7.3	12.5	0.5	20.3
	7.3	11.9	0	19.2
	7.3	12.2	0	19.5
	7.3	12.2	0	19.5
	7.3	12.1	0	19.4
	7.3	12.7	0	20.0
	7.3	12.7	0	20.0
	7.3	12.8	0	20.1
Aver.....	7.3	12.4	0.1	
	7.4	12.4	0	19.8
	7.4	12.4	0	19.8
	7.4	13.2	0	20.6
	7.4	12.1	0	19.5
	7.4	12.6	0	20.0
	7.4	13.6	0	21.0
	7.4	12.8	0	20.2
	*7.4	10.6	0	18.0
	7.4	12.3	0	19.7
	7.4	12.7	0	20.1
	7.4	12.0	0	19.4
	7.4	12.5	0	19.9
	7.4	12.6	0	20.0
	7.4	11.9	0	19.3
	7.4	12.6	0	20.0
	7.4	12.7	0.1	20.2
	7.4	12.0	0	19.4
	7.4	12.8	0	20.2
Aver.....	7.4	12.4	0	
	7.5	12.5	0	20.0
	7.5	12.6	0	20.1
	7.5	12.6	0	20.1
	7.5	12.5	0	20.0
	7.5	12.3	0	19.8
	7.5	11.5	0	19.0
	7.5	12.1	0	19.6
	7.5	11.7	0	19.2
	7.5	12.6	0.1	20.2
	7.5	12.2	0	19.7
Aver.....	7.5	12.3	0	
	7.6	12.4	0	20.0
	7.6	12.2	0	19.8
	*7.6	10.5	0	18.1

Continued on next page

TABLE 2—Continued

ARRANGED ACCORDING TO O

	O	CO_2	CO	Total
		Contined		
	12.6	7.8	0	20.4
	12.6	7.6	0	20.2
	12.6	7.6	0	20.2
	12.6	7.6	0	20.2
	12.6	7.5	0.1	20.2
	12.6	8.0	0	20.6
	12.6	7.9	0	20.5
	12.6	7.9	0	20.5
	12.6	6.6	0	19.2
	12.6	7.0	0.1	19.7
Aver.....	12.6	7.5	0	
	12.5	7.2	0.6	20.3
	12.5	7.2	0	19.7
	12.5	6.6	0	19.1
	12.5	8.5	0	21.0
	12.5	7.6	0.1	20.2
	12.5	7.6	0	20.1
	12.5	7.5	0	20.0
	12.5	7.4	0	19.9
	12.5	7.3	0.5	20.3
	12.5	7.2	0	19.7
Aver.....	12.5	7.4	0.1	
	12.4	7.1	0	19.5
	12.4	7.0	0	19.4
	12.4	7.4	0	19.8
	12.4	7.4	0	19.8
	12.4	7.8	0	20.2
	12.4	7.7	0	20.1
	12.4	7.6	0	20.0
	12.4	7.6	0	20.0
	12.4	7.6	0.2	20.2
	12.4	7.6	0	20.0
	12.4	7.6	0	20.0
	12.4	8.0	0	20.4
	12.4	8.0	0	20.4
	12.4	8.0	0	20.4
	12.4	7.9	0	20.3
	12.4	8.2	0	20.6
	12.4	8.2	0	20.6
	12.4	8.2	0.3	20.9
	12.4	8.6	0	21.1
	12.4	7.6	0	20.0
Aver.....	12.4	7.8	0	
	12.3	8.2	0	20.5
	12.3	8.0	0.3	20.6
	12.3	7.8	0	20.1

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U. S. Government Tests

TABLE 1—Continued

Arranged According to CO_2

	CO_2	O	CO	Total
		Continued		
	7.6	12.6	0	20.2
	7.6	12.7	0	20.3
	7.6	12.4	0	20.0
	7.6	12.7	0	20.3
	7.6	11.5	0	19.1
	7.6	12.4	0	20.0
	7.6	12.5	0.1	20.2
	7.6	12.5	0	20.1
	7.6	12.4	0.2	20.2
	7.6	11.5	0.3	19.4
	7.6	12.6	0	20.2
	7.6	12.3	0	19.9
	7.6	12.6	0	20.2
	7.6	12.2	0	19.8
	*7.6	10.5	0	18.1
	†7.6	11.0	0.4	19.0
	7.6	12.9	0	20.5
	7.6	12.4	0	20.0
	7.6	11.8	0	19.4
	7.6	12.1	0	19.7
	7.6	12.0	0	19.6
	7.6	12.8	0	20.4
	7.6	11.7	0	19.3
	7.6	12.8	0	20.4
	7.6	12.7	0.3	20.6
	7.6	12.4	0	20.0
	7.6	12.9	0	20.5
	7.6	12.6	0	20.2
Aver.	7.6	12.2	0	
	7.7	12.4	0	20.1
	7.7	11.9	0	19.6
	†7.7	12.0	0.5	20.2
Aver.	7.7	12.1	0.2	
	7.8	11.8	0	19.6
	7.8	13.0	0	20.8
	7.8	11.5	0.2	19.5
	7.8	12.3	0	20.1
	7.8	11.9	0	19.7
	7.8	11.2	0	19.0
	7.8	12.0	0	19.8
	7.8	11.4	0.2	19.4
	7.8	13.0	0	20.8
	7.8	11.2	0	19.0
	7.8	12.6	0	20.4
	7.8	12.6	0	20.4
	7.8	12.4	0	20.2
	7.8	12.6	0	20.4
Aver.	7.8	12.1	0	

TABLE 2—Continued

Arranged According to O

	O	CO_2	CO	Total
		Continued		
	12.3	7.6	0	19.9
	12.3	7.5	0	19.8
	12.3	7.4	0	19.7
	12.3	7.3	0.5	20.1
Aver.	12.3	7.6	0.1	
	12.2	6.6	0	18.8
	12.2	7.1	0	19.3
	12.2	7.0	0	19.2
	12.2	6.9	0	19.1
	12.2	7.3	0	19.5
	12.2	7.3	0	19.5
	12.2	7.3	0	19.5
	12.2	7.6	0	19.8
	12.2	7.6	0	19.8
	12.2	7.5	0	19.7
	12.2	8.1	0	20.3
	12.2	8.2	0.1	20.5
	12.2	7.2	0	19.4
Aver.	12.2	7.4	0	
	12.1	8.2	0	20.3
	12.1	8.0	0	20.1
	12.1	8.0	0.2	20.3
	12.1	7.6	0	19.7
	12.1	7.5	0	19.6
	12.1	7.4	0	19.5
	12.1	7.3	0	19.4
	12.1	7.2	0	19.3
Aver.	12.1	7.7	0	
	12.0	7.2	0	19.2
	12.0	7.4	0	19.4
	12.0	7.4	0	19.4
	12.0	7.8	0	19.8
	12.0	7.7	0.5	20.2
	12.0	7.6	0	19.6
	12.0	8.0	0	20.0
	12.0	8.0	0.1	20.1
	12.0	7.9	0	19.9
	12.0	7.9	0	19.9
	12.0	8.2	0	20.2
	12.0	8.2	0	20.2
	12.0	8.4	0	20.4
	12.0	8.0	0	20.0
Aver.	12.0	7.1	0	
	11.9	8.4	0	20.3
	11.9	8.5	0	20.4
	11.9	8.2	0	20.1

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U. S. Government Tests

TABLE 1—Continued

Arranged According to CO_2

	CO_2	O	CO	Total
	7.9	12.6	0	20.5
	7.9	12.8	0	20.7
	7.9	12.6	0	20.5
	7.9	11.7	0.3	19.9
	7.9	11.9	0.1	19.9
	7.9	11.7	0	19.6
	7.9	12.0	0	19.9
	7.9	11.6	0.3	19.8
	7.9	11.8	0.2	19.9
	7.9	11.5	0	19.4
	7.9	11.9	0.2	20.0
	7.9	11.7	0.1	19.7
	7.9	11.3	0.1	19.3
	7.9	11.6	0	19.5
	7.9	11.5	0	19.4
	†7.9	10.4	0.5	18.8
	*7.9	10.6	0	18.5
	7.9	12.4	0	20.3
	7.9	11.9	0	19.8
	7.9	12.0	0	19.9
Aver.....	7.9	11.8	0.1	
	8.0	11.9	0	19.9
	8.0	11.6	0	19.3
	8.0	11.8	0.3	20.1
	8.0	11.9	0.1	20.0
	*8.0	10.4	0.1	18.5
	8.0	12.4	0	20.4
	8.0	12.6	0	20.6
	8.0	12.0	0	20.0
	8.0	12.0	0.1	20.1
	8.0	12.1	0.2	20.3
	8.0	11.7	0	19.7
	8.0	11.0	0.1	19.1
	8.0	12.0	0	20.0
	8.0	11.3	0	19.3
	8.0	11.6	0	19.6
	8.0	11.7	0	19.7
	8.0	11.2	0	19.2
	8.0	11.3	0	19.3
	8.0	11.8	0	19.8
	8.0	12.3	0.3	20.6
	*8.0	10.0	0	18.0
	8.0	11.4	0	19.4
	8.0	11.8	0	19.8
	8.0	11.8	0.1	19.9
	8.0	12.4	0	20.4
	8.0	12.4	0	20.4
	8.0	11.9	0	19.9
	8.0	11.8	0	19.8
	8.0	12.1	0	20.1
	8.0	11.4	0	19.4
Aver.....	8.0	11.7	0	

TABLE 2—Continued

Arranged According to O

	O	CO_2	CO	Total
		Continued		
	11.9	8.2	0	20.1
	11.9	8.0	0	19.9
	11.9	8.0	0.1	20.0
	11.9	8.0	0	19.9
	11.9	7.9	0	19.8
	11.9	7.9	0.2	20.0
	11.9	7.9	0.1	19.9
	11.9	7.8	0	19.7
	11.9	7.7	0	19.6
	11.9	7.4	0	19.3
	11.9	7.3	0	19.2
	11.9	7.2	0	19.1
	11.9	7.0	0.1	19.0
	11.9	8.9	0	20.8
Aver.....	11.9	7.9	0	
	11.8	7.8	0	19.6
	11.8	7.6	0	19.4
	11.8	8.0	0	19.8
	11.8	8.0	0	19.8
	11.8	8.0	0.1	19.9
	11.8	8.0	0	19.8
	11.8	8.0	0.3	20.1
	11.8	7.9	0.2	19.9
	11.8	8.3	0.3	20.4
	11.8	8.3	0	20.1
	11.8	8.2	0	20.0
	11.8	8.2	0	20.0
	11.8	8.4	0.3	20.5
	11.8	8.4	0.2	20.4
	11.8	8.4	0	20.2
	11.8	8.8	0.3	20.9
Aver.....	11.8	8.1	0.1	
	11.7	8.7	0.1	20.5
	11.7	8.4	0.2	20.3
	11.7	8.3	0	20.0
	11.7	8.3	0	20.0
	11.7	8.1	0	19.8
	11.7	8.0	0	19.7
	11.7	8.0	0	19.7
	11.7	7.9	0.1	19.7
	11.7	7.9	0.3	19.9
	11.7	7.9	0	19.6
	11.7	7.6	0	19.3
	11.7	7.5	0	19.2
Aver.....	11.7	8.1	0.1	

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TABLE 1—Continued

Arranged According to CO_2

	CO_2	O	CO	Total
	8.1	11.7	0	19.8
	8.1	11.2	0.2	19.5
	*8.1	10.3	0.2	18.6
	8.1	12.2	0	20.3
	8.1	11.3	0.3	19.7
	†8.1	10.8	0.5	19.4
	8.1	11.5	0.1	19.7
Aver	8.1	11.3	0.2	
	8.2	12.4	0.3	20.9
	8.2	12.0	0	20.2
	8.2	11.1	0.1	19.4
	*8.2	10.2	0.1	18.5
	†8.2	11.4	0.4	20.0
	†8.2	11.0	0.4	19.6
	8.2	11.2	0.2	19.6
	†8.2	11.4	0.5	20.1
	†8.2	11.1	0.4	19.7
	8.2	11.9	0	20.1
	8.2	11.8	0	20.0
	8.2	11.0	0	19.2
	8.2	12.4	0	20.6
	8.2	11.3	0	19.5
	8.2	12.1	0	20.3
	8.2	12.0	0	20.2
	8.2	12.2	0.1	20.5
	8.2	12.4	0	20.6
	8.2	11.6	0	19.8
	8.2	11.2	0	19.4
	8.2	11.8	0	20.0
	8.2	11.6	0	19.8
	†8.2	10.8	0.4	19.4
	8.2	10.7	0	18.9
	8.2	11.3	0	19.5
	8.2	12.1	0.3	20.6
	8.2	12.3	0	20.5
	8.2	11.6	0	19.8
	8.2	11.0	0.3	19.5
	8.2	12.3	0	20.5
	8.2	11.9	0	20.1
Aver	8.2	11.6	0.1	
	8.3	11.3	0	19.6
	8.3	11.8	0	20.1
	8.3	11.3	0	19.6
	8.3	11.7	0	20.0
	†8.3	11.5	0.4	20.2
	8.3	11.8	0.3	20.4

Continued on next page

TABLE 2—Continued

Arranged According to O

	O	CO_2	CO	Total
	11.6	8.0	0	19.6
	11.6	8.0	0	19.6
	11.6	7.9	0	19.5
	11.6	7.9	0.3	19.8
	11.6	9.1	0	20.7
	11.6	9.0	0	20.6
	11.6	9.0	0.2	20.8
	11.6	8.3	0	19.9
	11.6	8.2	0	19.8
	11.6	8.2	0	19.8
	11.6	8.2	0	19.8
	11.6	8.5	0	20.1
	11.6	8.4	0	20.0
	11.6	8.8	0	20.4
	11.6	8.8	0.2	20.6
	11.6	8.7	0.3	20.6
Aver	11.6	8.4	0.1	
	11.5	8.8	0.3	20.6
	11.5	8.9	0	20.4
	11.5	8.6	0.1	20.2
	11.5	8.5	0.2	20.2
	11.5	8.4	0	19.9
	11.5	8.3	0.4	20.2
	11.5	8.1	0.1	19.7
	11.5	7.9	0	19.4
	11.5	7.9	0	19.4
	11.5	6.7	0	18.2
	11.5	7.8	0.2	19.5
	11.5	7.6	0.3	19.4
	11.5	7.5	0	19.0
Aver.	11.5	8.1	0.1	
	11.4	7.8	0.2	19.4
	11.4	8.0	0	19.4
	11.4	8.0	0	19.4
	11.4	8.2	0.5	20.1
	11.4	8.2	0.4	20.0
	11.4	8.5	0	19.9
	11.4	8.5	0	19.9
	11.4	8.4	0.2	20.0
	11.4	8.4	0	19.8
	11.4	8.4	0	19.8
	11.4	8.4	0	19.8
	11.4	8.4	0.2	20.0
	11.4	8.4	0	19.8
	11.4	8.9	0	20.3
	11.4	8.9	0	20.3
Aver	11.4	8.4	0.1	

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TABLE 1—Continued

Arranged According to CO_2

	CO_2	O	CO	Total
		Continued		
	8.3	11.7	0	20.0
	8.3	12.7	0	21.0
	8.3	11.1	0.2	19.6
	8.3	10.8	0	19.1
	8.3	9.7	0	18.0
	†8.3	10.1	0.8	19.2
	†8.3	10.5	0.5	19.3
	8.3	11.9	0.1	20.3
	8.3	11.6	0	19.9
Aver.....	8.3	11.3	0.2	
	8.4	10.8	0	19.2
	*8.4	10.2	0	18.6
	8.4	11.8	0	20.2
	8.4	11.3	0.1	19.8
	8.4	11.4	0.2	20.0
	8.4	11.4	0	19.8
	8.4	12.5	0.1	21.0
	8.4	11.6	0	20.0
	8.4	11.7	0.2	20.3
	8.4	11.8	0.2	20.4
	8.4	11.5	0	19.9
	8.4	11.9	0	20.3
	8.4	11.4	0	19.8
	8.4	11.0	0	19.4
	8.4	11.4	0	19.8
	8.4	11.0	0.5	19.9
	8.4	10.2	0.2	18.8
	†*8.4	9.9	0.5	18.8
	8.4	11.0	0	19.4
	8.4	11.0	0.2	19.6
	†8.4	11.3	0.4	20.1
	*8.4	9.9	0	18.3
	8.4	12.0	0	20.4
	8.4	11.4	0	19.8
	8.4	11.8	0.3	20.5
	8.4	11.4	0.2	20.0
	8.4	11.3	0	19.7
Aver.....	8.4	11.3	0.1	
	8.5	11.5	0.2	20.2
	8.5	12.5	0	21.0
	8.5	10.9	0	19.4
	8.5	12.3	0	20.8
	8.5	11.4	0	19.9
	8.5	11.6	0	20.1
	8.5	11.0	0.3	19.8
	8.5	11.9	0	20.4
	†8.5	10.3	0.3	19.1
	8.5	11.4	0	19.9
Aver.....	8.5	11.5	0.1	

TABLE 2—Continued

Arranged According to O

	O	CO_2	CO	Total
	11.3	8.7	0	20.0
	11.3	8.8	0	20.1
	11.3	8.9	0	20.2
	11.3	8.4	0	19.7
	11.3	8.4	0.4	20.1
	11.3	8.4	0.1	19.8
	11.3	8.3	0	19.6
	11.3	8.3	0	19.6
	11.3	8.2	0	19.5
	11.3	8.2	0	19.5
	11.3	8.1	0.3	19.7
	11.3	8.0	0	19.3
	11.3	8.0	0	19.3
	11.3	7.9	0.1	19.3
Aver.....	11.3	8.3	0.1	
	11.2	7.8	0	19.0
	*11.2	6.8	0	18.0
	*11.2	6.6	0	17.8
	11.2	8.2	0.2	19.6
	11.2	8.2	0	19.4
	11.2	9.0	0.2	20.4
	11.2	8.6	0	19.8
	11.2	8.6	0.2	20.0
	11.2	8.9	0	20.1
	11.2	8.8	0	20.0
	11.2	8.8	0	20.0
	11.2	8.6	0	19.8
	11.2	9.0	0	20.2
	11.2	7.8	0	19.0
Aver.....	11.2	8.3	0	
	11.1	8.9	0	20.0
	11.1	8.9	0.3	20.3
	11.1	8.9	0	20.0
	11.1	8.6	0	19.7
	11.1	8.6	0.1	19.8
	11.1	8.3	0.2	19.6
	11.1	8.2	0.4	19.7
	11.1	8.2	0.1	19.4
	11.1	9.3	0	20.4
	*11.1	6.8	0.1	18.0
Aver.....	11.1	8.5	0.1	
	11.0	8.2	0.3	19.5
	11.0	7.6	0.4	19.0
	11.0	9.4	0	20.4
	11.0	8.6	0	19.6
	11.0	8.6	0.2	19.8
	11.0	8.6	0	19.6
	11.0	8.6	0.4	20.0

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U. S. Government Tests

TABLE 1—Continued

ARRANGED ACCORDING TO CO_2

	CO_2	O	CO	Total
	8.6	11.2	0	19.8
	8.6	10.5	0	19.1
	8.6	11.5	0.1	20.2
	8.6	11.2	0.2	20.0
	†8.6	11.0	0.4	20.0
	8.6	11.1	0.1	19.8
	†8.6	10.8	0.5	19.9
	8.6	10.7	0.2	19.5
	8.6	10.8	0	19.4
	8.6	11.0	0	19.6
	8.6	10.6	0	19.2
	8.6	12.4	0	21.0
	8.6	11.2	0	19.8
	8.6	11.1	0	19.7
	8.6	11.0	0	19.6
	8.6	11.0	0.2	19.8
Aver.....	8.6	11.1	0.1	
	8.7	11.7	0.1	20.5
	8.7	11.0	0	19.7
	8.7	11.3	0	2.00
	8.7	10.2	0.1	19.0
	8.7	11.0	0.0	19.7
	8.7	10.7	0.3	19.7
	8.7	10.8	0	19.5
	8.7	11.6	0.3	20.6
	8.7	10.5	0	19.2
	8.7	10.4	0	19.1
	8.7	10.7	0.4	19.8
	8.7	10.6	0	09.3
Aver.....	8.7	10.9	0.1	
	8.8	11.0	0	19.8
	8.8	11.6	0.2	20.6
	8.8	10.8	0.3	19.9
	8.8	10.8	0	19.6
	*8.8	10.2	0.3	18.3
	8.8	10.5	0.2	19.5
	*8.8	9.0	0	17.8
	8.8	11.2	0	20.0
	8.8	10.7	0.3	19.8
	8.8	10.9	0.2	19.9
	8.8	11.2	0	20.0
	8.8	11.6	0	20.4
	8.8	11.3	0	20.1
	†*8.8	9.2	0.6	18.6
	8.8	11.5	0.3	20.6
	8.8	11.8	0.3	20.9
	8.8	10.8	0.1	19.7
Aver.....	8.8	10.8	0.2	

TABLE 2—Continued

ARRANGED ACCORDING TO O

O	CO_2	CO	Total
	Continued		
11.0	8.5	0.3	19.8
11.0	8.4	0	19.4
11.0	8.4	0.2	19.6
11.0	8.4	0.5	19.9
11.0	8.4	0	19.4
11.0	8.7	0	19.7
11.0	8.7	0	19.7
11.0	8.8	0	19.8
11.0	8.8	0.4	19.6
11.0	9.0	0.3	20.3
11.0	8.0	0.1	19.1
Aver..... 11.0	8.5	0.3	
10.9	9.0	0	19.9
10.9	9.0	0	19.9
10.9	9.2	0	20.1
10.9	8.5	0	19.4
10.9	8.8	0.2	19.9
Aver..... 10.9	8.9	0	
10.8	8.8	0.1	19.7
10.8	8.8	0.3	19.9
10.8	8.8	0	19.6
10.8	8.7	0	19.5
10.8	8.3	0	19.1
10.8	8.2	0.4	19.4
10.8	8.1	0.5	19.4
10.8	8.6	0	19.4
10.8	8.6	0.5	19.9
10.8	8.4	0	19.2
10.8	9.0	0	19.8
10.8	9.0	0	19.8
10.8	9.1	0.1	20.0
10.8	9.1	0.2	20.1
Aver..... 10.8	8.7	0.2	
10.7	9.2	0.3	20.2
10.7	9.2	0	19.9
10.7	9.1	0	19.8
10.7	8.6	0.2	19.5
10.7	9.4	0.1	20.2
10.7	8.2	0	19.9
10.7	8.8	0.3	19.8
10.7	8.7	0.4	19.8
10.7	8.7	0.3	19.7
10.7	9.0	0	19.7
Aver..... 10.7	8.9	0.2	

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TABLE 1—Continued

Arranged According to CO_2

	CO_2	O	CO	Total
	8.9	11.1	0	20.0
	8.9	11.5	0	30.4
	8.9	11.9	0	20.8
	8.9	11.2	0	20.1
	8.9	11.4	0	20.3
	8.9	10.5	0.2	19.6
	†8.9	10.5	0.4	19.8
	8.9	11.1	0.3	20.3
	8.9	11.4	0	20.3
	*8.9	9.8	0.2	18.9
	8 9	10.6	0	19.5
	8.9	11.3	0	20.2
	8.9	10.3	0	19.2
	8.9	11.1	0	20.0
Aver.	8.9	11.0	0.1	
	9.0	11.2	0	20.2
	9.0	10.9	0	19.9
	9.0	10.7	0	19 7
	9.0	10.8	0	19.8
	9 0	10.5	0	19.5
	9.0	10.0	0	19.0
	9.0	10.8	0	19.8
	†9.0	9.8	0.4	19.2
	9 0	10.5	0	19.5
	9.0	10.6	0	19.6
	9.0	10.6	0.3	19.9
	†9.0	10.3	0 4	19.7
	9.0	11.0	0 3	20.3
	†9.0	9.6	0.4	19.0
	9 0	11.2	0.2	20.4
	9 0	11 6	0	20.6
	9.0	11.6	0.2	20.8
	9 0	10 9	0	19.9
	9.0	10.4	0	19.4
Aver.....	9.0	10.7	0.1	
	9.1	10.7	0	19.8
	9.1	10 5	0.2	19.8
	†9.1	10.3	0.5	19.9
	9 1	10.8	0.1	20.0
	9.1	11.6	0	20 7
	9.1	10.2	0	19.3
	9.1	10.8	0.2	20.1
	*9.1	9 7	0	18.8
	9.1	10.5	0	19.6
	†9.1	10.3	0.5	19.9
	9.1	10.1	0.3	19.5
	9.1	10.6	0.1	19.8
Aver.....	9.1	10.5	0.2	

TABLE 2—Continued

Arranged According to O

	O	CO_2	CO	Total
	*10.6	7.4	0	18.0
	*10.6	6.8	0	17.4
	10.6	7.9	0	19.5
	10.6	8.9	0	19.5
	10.6	9.4	0.2	20 2
	10.6	9.4	0.4	20.4
	10.6	8.6	0	19.2
	10.6	9.0	0	19.6
	10.6	9.0	0.3	19.9
	10.6	9.1	0 1	19.8
	10.6	9.2	0.1	19.9
	10.6	9.2	0	19.8
	10.6	9.2	0.2	20.0
	10.6	8 7	0	19.3
	*10.6	7.2	0	17.8
Aver..	10.6	8.6	0.1	
	10.5	9.0	0	19.5
	10.5	9.0	0	19.5
	10.5	9.1	0.2	19.8
	10.5	9.1	0	19.6
	10.5	9.2	0.1	19.8
	10.5	8.6	0	19.1
	10.5	9.4	0 3	20.2
	10.5	9.3	0.4	20.2
	10.5	8.3	0.5	19.3
	*10.5	7.6	0	18.1
	10 5	8.9	0.2	19.6
	10.5	8.9	0.4	19 8
	10.5	8.8	0 2	19.5
	10.5	8.7	0	19.2
Aver.....	10.5	8.9	0.2	
	10.4	8.0	0.1	18.5
	*10.4	7.9	0.5	18.8
	10.4	8.7	0	19.1
	10.4	9.3	0.5	20.2
	10.4	9 4	0	19.8
	10.4	9.5	0	19.9
	10.4	9.6	0.2	20.2
	10.4	9.2	0.2	20.0
	10.4	9.2	0	19.6
	10.4	9.2	0.2	19.8
	10 4	9.0	0	19 4
Aver.	10.4	9.0	0.2	
	10.3	9.2	0	19.5
	10.3	9 2	0.3	19.8
	10.3	9.1	0.5	19 9
	10.3	9.1	0.5	19 9
	10.3	9.0	0.4	19.7

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TABLE 1—Continued

Arranged According to CO_2

	CO_2	O	CO	Total
	9.2	10.7	0	19.9
	9.2	10.6	0.1	19.9
	9.2	10.4	0.2	19.8
	9.2	10.6	0	19.8
	9.2	10.2	0.1	19.4
	9.2	10.5	0.1	19.8
	9.2	10.7	0.3	20.2
	9.2	10.6	0.2	20.0
	9.2	10.4	0	19.6
	9.2	10.9	0	20.1
	9.2	10.4	0.2	19.8
	9.2	10.3	0	19.5
	9.2	10.3	0.3	19.8
	*† 9.2	9.2	0.4	18.8
Aver.	9.2	10.4	0.1	
	† 9.3	9.8	0.4	19.5
	* 9.3	8.7	0.2	18.2
	9.3	10.0	0.2	19.5
	† 9.3	10.5	0.4	20.2
	† 9.3	10.4	0.5	20.2
	9.3	10.2	0	19.5
	9.3	10.3	0.3	19.9
	* 9.3	9.3	0	18.6
	† 9.3	9.8	0.5	19.6
	9.3	11.1	0	20.4
	9.3	10.3	0	19.6
Aver.	9.3	10.0	0.2	
	9.4	9.7	0	19.1
	9.4	9.6	0	19.0
	9.4	10.9	0.1	20.4
	9.4	10.4	0	19.8
	9.4	10.6	0.2	20.2
	9.4	11.0	0	20.4
	9.4	9.4	0.3	19.1
	9.4	10.5	0.3	20.2
	9.4	9.9	0.3	19.6
	† 9.4	10.6	0.4	20.4
	9.4	10.7	0.1	20.2
	† 9.4	10.2	0.4	20.0
	* 9.4	9.5	0	18.9
	9.4	10.1	0.1	19.6
	9.4	9.6	0.2	19.2
	9.4	9.6	0.3	19.3
Aver.	9.4	10.1	0.2	

TABLE 2—Continued

Arranged According to O

	O	CO_2	CO	Total
	Continued			
	10.3	8.5	0.3	19.1
	10.3	9.3	0.3	19.9
	10.3	9.3	0	19.6
	10.3	9.5	0.2	20.0
	10.3	9.6	0	19.9
	10.3	8.1	0.2	18.6
	10.3	8.9	0	19.2
Aver.	10.3	9.1	0.2	
	* 10.2	8.2	0.1	18.5
	10.2	9.3	0	19.5
	10.2	8.7	0.1	19.0
	10.2	8.8	0.3	19.9
	10.2	9.6	0	19.8
	10.2	10.2	0.6	21.0
	*10.2	8.4	0.2	18.8
	10.2	9.1	0	19.3
	10.2	9.2	0	19.4
	10.2	8.4	0	18.6
Aver.	10.2	9.0	0.1	
	10.1	9.1	0.3	19.5
	10.1	9.4	0.1	19.6
	10.1	8.3	0.8	19.2
Aver.	10.1	8.9	0.4	
	*10.0	8.0	0	18.0
	10.0	9.7	0.5	20.0
	10.0	9.6	0	19.6
	10.0	9.3	0.2	19.5
	10.0	10.2	0.1	20.3
	10.0	10.2	0	20.2
	10.0	9.0	0	19.0
Aver.	10.0	9.4	0.1	
	9.9	9.4	0.3	19.6
	9.9	9.5	0.4	19.8
	9.9	9.5	0.1	19.5
	9.9	9.6	0.2	19.7
	9.9	10.2	0.6	20.7
	9.9	10.2	0	20.1
	9.9	9.8	0.2	19.9
	* 9.9	8.4	0.5	18.8
	9.9	8.4	0	19.3
Aver.	9.9	9.4	0.3	
	9.8	9.8	0	19.6
	9.8	9.0	0.4	19.2
	9.8	9.6	0.1	19.5
	9.8	9.6	0	19.4

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TABLE 1—Continued

ARRANGED ACCORDING TO CO_2

	CO_2	O	CO	Total
	†9.5	9.3	0.5	19.3
	†9.5	9.9	0.4	19.8
	*9.5	8.5	0	18.0
	†9.5	9.3	0.6	19.4
	*9.5	8.9	0.1	18.5
	9.5	10.4	0	19.9
	†9.5	9.3	0.5	19.3
	9.5	9.9	0.1	19.5
	9.5	10.3	0.2	20.0
Aver.....	9.5	9.4	0.3	
	9.6	9.6	0	19.2
	9.6	9.8	0.1	19.5
	9.6	9.8	0	19.4
	9.6	10.0	0	19.6
	†9.6	9.6	0.8	20.0
	9.6	9.9	0.2	19.7
	9.6	9.4	0.2	19.2
	9.6	10.2	0	19.8
	9.6	10.3	0	19.9
	9.6	10.4	0.2	20.2
Aver.....	9.6	9.9	0.2	
	†9.7	10.0	0.5	20.2
	†9.7	9.5	0.4	19.6
Aver.....	9.7	9.8	0.5	
	9.8	9.6	0.2	19.6
	†9.8	9.3	0.4	19.7
	9.8	9.9	0.2	19.9
	9.8	9.8	0	19.6
	9.8	9.7	0.3	19.8
	9.8	9.7	0	19.5
	†9.8	9.2	0.4	19.4
	*9.8	8.2	0.3	18.3
Aver	9.8	9.4	0.2	
	9.9	8.9	0.6	19.4
	9.9	9.7	0.1	19.7
	†9.9	9.7	0.3	19.9
	†9.9	8.8	0.4	19.1
	*9.9	8.0	0	17.9
	†9.9	8.2	1.4	19.5
	9.9	9.6	0	19.5
Aver.....	9.9	9.0	0.4	

TABLE 2—Continued

ARRANGED ACCORDING TO O

	O	CO_2	CO	Total
		Continued		
	9.8	9.3	0.5	19.6
	9.8	9.3	0.4	19.5
	*9.8	8.9	0.2	18.9
Aver.....	9.8	9.4	0.3	
	9.7	9.4	0	19.1
	*9.7	9.1	0	18.8
	*9.7	8.3	0	18.0
	9.7	9.8	0.3	19.8
	9.7	9.8	0	19.5
	9.7	9.9	0.1	19.7
	9.7	9.9	0.3	19.9
Aver	9.7	9.5	0.1	
	9.6	10.1	0.3	20.0
	9.6	9.9	0	19.5
	9.6	9.8	0.2	19.6
	9.6	9.6	0.0	19.2
	9.6	9.4	0.2	19.2
	9.6	9.4	0.3	19.3
	9.6	9.4	0	19.0
	9.6	9.6	0.8	20.0
	9.6	9.0	0.4	19.0
Aver.....	9.6	9.6	0.2	
	9.5	10.1	0.4	20.0
	9.5	10.1	0	19.6
	9.5	9.7	0.4	19.6
	9.5	10.4	0	19.9
Aver.....	9.5	10.1	0.2	
	9.4	9.4	0.3	19.1
	9.4	9.6	0.2	19.2
	9.4	10.4	0.1	19.9
	9.4	10.2	0	19.6
	9.4	10.0	0.2	19.6
	9.4	10.0	0	19.4
	9.4	10.0	0.3	19.7
Aver. . ..	9.4	9.9	0.2	
	9.3	9.8	0.4	19.7
	9.3	10.5	0.2	20.0
	9.3	10.5	0.4	20.2
	9.3	9.5	0.5	19.3
	*9.3	9.3	0	18.6
	9.3	9.5	0.5	19.3
Aver.....	9.3	9.9	0.3	

U. S. Government Tests

TABLE 1—Continued

Arranged According to CO_2

	CO_2	O	CO	Total
	10.0	9.4	0	19.4
	†10.0	9.4	0.3	19.7
	10.0	9.2	0	19.2
	†10.0	9.0	0.3	19.3
	*10.0	8.6	0	18.6
	10.0	9.4	0.2	19.6
	†10.0	9.2	0.4	19.6
	†10.0	9.0	0.3	19.3
Aver.....	10.0	9.2	0.2	
	*10.1	7.0	0.2	17.3
	10.1	9.6	0.3	20.0
	†10.1	8.9	1.6	20.6
	†10.1	8.6	2.1	20.8
	10.1	9.5	0	19.6
	10.1	9.0	0.3	19.4
	†10.1	9.5	0.4	20.0
	†*10.1	8.2	0.4	18.7
Aver.....	10.1	8.8	0.7	
	10.2	10.0	0	20.2
	10.2	9.9	0	20.1
	10.2	10.0	0.1	20.3
	10.2	9.4	0	19.6
	†10.2	9.9	0.6	20.7
	†10.2	10.2	0.6	21.0
Aver.....	10.2	9.9	0.2	
	*10.3	7.7	0	18.0
	†10.4	8.9	0.5	19.8
	†10.4	8.6	1.4	20.4
	10.4	9.5	0	19.9
	†10.4	9.0	0.5	19.5
	†10.4	8.2	0.5	19.1
	10.4	8.9	0.2	19.5
	10.4	9.4	0.1	19.9
Aver.....	10.4	8.9	0.5	
	10.5	9.3	0.2	20.0
	†10.5	9.3	0.4	20.2
	†*10.5	7.7	0.6	18.8
	†10.5	8.6	0.5	19.6
Aver.....	10.5	8.7	0.4	
	10.6	0	0	19.6
	10.7	9.1	0.2	20.0
	†10.7	7.9	0.9	19.5
	10.7	8.1	1.1	19.9
Aver.....	10.7	8.4	0.7	

TABLE 2—Continued

Arranged According to O

	O	CO_2	CO	Total
	*9.2	8.8	0.6	18.6
	9.2	10.0	0.4	19.6
	*9.2	7.1	0.3	16.7
	9.2	10.0	0	19.2
	9.2	9.8	0.4	19.4
	*9.2	9.2	0.4	18.8
Aver.....	9.2	9.2	0.4	
	9.1	10.7	0.2	20.0
	9.1	10.1	0.3	20.5
Aver	9.1	10.4	0.2	
	*9.0	8.8	0	17.8
	9.0	10.6	0	19.6
	9.0	10.4	0.5	19.5
	9.0	10.1	0.3	19.4
	9.0	10.0	0.3	19.3
	9.0	10.0	0.3	19.3
Aver'.....	9.0	10.0	0.2	
	8.9	9.9	0.6	19.4
	8.9	10.1	1.6	19.7
	8.9	10.4	0.5	19.8
	8.9	10.4	0.2	19.5
	* 8.9	9.5	0.1	18.5
Aver.....	8.9	10.0	0.6	
	8.8	9.9	0.4	19.1
	8.8	11.0	0.5	20.3
	8.8	11.0	0	19.8
Aver	8.8	10.6	0.3	
	* 8.7	9.3	0.2	18.2
	8.7	10.8	0	19.5
Aver.....	8.7	10.0	0.1	
	8.6	10.1	2.1	20.8
	8.6	10.8	0	19.4
	8.6	10.8	0	19.4
	8.6	10.5	0.5	19.6
	8.6	10.4	1.4	20.4
	* 8.6	10.0	0	18.6
Aver.....	8.6	10.4	0.7	
	* 8.5	9.5	0	18.0
	8.3	10.8	0.1	19.2

U. S. Government Tests

TABLE 1—Continued

Arranged According to CO_2

	CO_2	O	CO	Total
	10.8	8.6	0	19.4
	10.8	8.6	0	19.4
	10.8	8.7	0	19.5
	10.8	8.3	0.1	19.2
Aver.....	10.8	8.6	0	
	10.9	7.9	0.3	19.1
	†11.0	8.8	0.5	20.3
	11.0	8.8	0	19.8
Aver.....	11.0	8.8	0.3	
	11.1	8.1	0.2	19.4
	11.1	9.1	0.3	20.5
Aver.....	11.1	8.6	0.3	
	†11.4	7.9	0.4	19.7

TABLE 2—Continued

Arranged According to O

	O	CO_2	CO	Total
	8.2	10.4	0.5	19.1
	8.2	10.1	0.4	18.7
	8.2	9.9	1.4	19.5
	8.2	9.8	0.3	18.3
Aver.....	8.2	10.0	0.6	
	8.1	10.7	1.1	19.9
	8.1	11.1	0.2	19.4
Aver.....	8.1	10.9	0.6	
	8.0	9.9	0	17.9
	7.9	10.7	0.9	19.5
	7.9	10.4	0.4	19.7
Aver.....	7.9	11.0	0.6	
	*7.7	10.5	0.6	18.8
	*7.0	10.1	0.2	17.3

Locomotive Tests[1]

TABLE 3

Arranged According to CO_2

CO_2	O	CO	Total
10.16	8.49	0.13	18.78
11.10	7.84	0.23	19.17
11.15	7.52	0.20	18.87
11.45	6.92	0	18.37
11.46	7.49	0.1	19.05
11.50	7.08	0.17	18.75
11.78	6.74	0.30	18.82
11.96	7.00	0.23	19.19
11.96	7.07	0.14	19.17
12.05	6.93	0.15	19.13
12.20	6.94	0.05	19.19
12.45	5.87	0.22	18.54
13.57	4.49	0.20	18.26
13.87	4.75	0.25	18.87

TABLE 4

Arranged According to O

O	CO_2	CO	Total
8.49	10.16	0.13	18.78
7.84	11.10	0.23	19.17
7.52	11.15	0.20	18.87
7.49	11.46	0.1	19.05
7.08	11.50	0.17	18.75
7.07	11.96	0.14	19.17
7.00	11.96	0.23	19.19
6.94	12.20	0.05	19.19
6.93	12.05	0.15	19.13
6.92	11.45	0	18.37
6.74	11.78	0.30	18.82
5.87	12.45	0.22	18.54
4.75	13.87	0.25	18.87
4.49	13.57	0.20	18.26

[1] Bulletin No. 367, U. S. Geological Survey, The Significance of Draft in Steam Boiler Practice.

Six Hour Average Samples

TABLE 5

Arranged According to CO_2

	CO_2	O	CO	Total
	8.2	11.4	0	19.6
	8.5	11.3	0	19.8
	8.8	10.6	0	19.4
	9.0	10.3	0	19.3
	9.0	10.2	0	19.2
Aver.	9.0	10.3	0	
	9.2	10.1	0	19.3
	9.2	10.1	0	19.3
Aver.	9.2	10.1	0	
	9.3	10.3	0	19.6
	9.3	9.8	0	19.1
Aver.	9.3	10.1	0	
	9.5	10.3	0	19.8
	9.6	9.6	0	19.2
	9.7	10.1	0	19.8
	9.8	9.8	0	19.6
	9.8	9.7	0	19.5
	9.8	9.7	0	19.5
Aver.	9.8	9.7	0	
	† 9.9	8.9	0.4	19.2
	10.0	9.9	0	19.9
	10.0	9.1	0	19.1
	10.0	9.0	0	19.0
	10.0	9.0	0	19.0
	10.0	9.5	0	19.5
	10.0	9.3	0	19.3
	10.0	9.3	0	19.3
Aver.	10.0	9.3	0	
	10.1	9.1	0	19.2
	10.1	9.8	0	19.9
Aver.	10.1	9.5	0	
	10.2	9.4	0	19.6
	10.2	9.3	0	19.5
	10.2	9.2	0	19.4
	10.2	9.1	0	19.3
Aver.	10.2	9.3	0	

TABLE 6

Arranged According to O

	O	CO_2	CO	Total
	11.4	8.2	0	19.6
	11.3	8.0	0	19.3
	11.3	8.5	0	19.8
Aver.	11.3	8.3	0	
	10.6	8.8	0	19.4
	10.3	9.0	0	19.3
	10.3	9.3	0	19.6
	10.4	9.5	0	19.8
Avser.	10.3	9.3	0	
	10.2	9.0	0	19.2
	10.1	9.2	0	19.3
	10.1	9.2	0	19.3
	10.1	9.7	0	19.8
Aver.	10.1	9.4	0	
	9.9	10.0	0	19.9
	9.8	9.3	0	19.1
	9.8	9.8	0	19.6
	9.8	10.1	0	19.9
Aver.	9.8	9.7	0	
	9.7	9.8	0	19.5
	9.7	9.8	0	19.5
Aver.	9.7	9.8	0	19.5
	9.6	9.6	0	19.2
	9.5	10.0	0	19.5
	9.4	10.2	0	19.6
	9.4	10.3	0	19.7
	9.4	10.6	0	20.0
Aver.	9.4	10.4	0	
	9.3	10.0	0	19.3
	9.3	10.0	0	19.3
	9.3	10.2	0	19.5
	9.3	10.3	0	19.6
	9.3	10.4	0	19.7
	9.3	10.4	0	19.7
	9.3	10.5	0	19.8
Aver.	9.3	10.3	0	

Six Hour Average Samples

TABLE 5—Continued

Arranged According to CO_2

	CO_2	O	CO	Total
	10.3	9.0	0	19.3
	10.3	9.0	0	19.3
	10.3	9.1	0	19.4
	10.3	9.1	0	19.4
	10.3	9.2	0	19.5
	10.3	8.6	0.1	19.0
	10.3	8.7	0	19.0
	10.3	8.7	0	19.0
	10.3	8.8	0	19.1
	10.3	9.4	0	19.7
	10.3	9.2	0	19.5
	10.3	9.3	0	19.6
Aver.....	10.3	9.0	0	
	10.4	9.3	0	19.7
	10.4	9.3	0	19.7
	10.4	8.7	0	19.1
	10.4	8.9	0	19.3
Aver.....	10.4	9.1	0	
	10.5	8.9	0	19.4
	10.5	9.0	0	19.5
	10.5	9.3	0	19.8
Aver.....	10.5	9.1	0	
	10.6	9.4	0	20.0
	10.6	9.2	0	19.8
	10.6	8.4	0	19.0
Aver.....	10.6	9.0	0	
	10.7	8.3	0	19.0
	10.7	8.8	0	19.5
	10.7	8.6	0	19.3
	10.7	8.3	0	19.0
Aver.....	10.7	8.5	0	
	10.8	8.4	0	19.2
	10.8	8.4	0	19.2
Aver.....	10.8	8.4	0	
	10.9	8.5	0	19.4
	10.9	8.2	0.2	19.1
Aver.....	10.9	8.4	0.1	
	11.0	8.8	0	19.8
	11.0	8.7	0	19.7
	11.0	8.1	0	19.1
	11.0	8.2	0	19.2
	11.0	8.0	0	19.0

Continued on next page

TABLE 6—Continued

Arranged According to O

	O	CO_2	CO	Total
	9.2	10.2	0	19.4
	9.2	10.3	0	19.5
	9.2	10.3	0	19.5
	9.2	10.6	0	19.8
Aver.....	9.2	10.4	0	
	9.1	10.0	0	19.1
	9.1	10.1	0	19.2
	9.1	10.2	0	19.3
	9.1	10.3	0	19.4
	9.1	10.3	0	19.4
Aver.....	9.1	10.2	0	
	9.0	10.0	0	19.0
	9.0	10.0	0	19.0
	9.0	10.3	0	19.3
	9.0	10.3	0	19.3
	9.0	10.5	0	19.5
Aver.....	9.0	10.2	0	
	8.9	9.9	0.4	19.2
	8.9	10.4	0	19.3
	8.9	10.5	0	19.4
Aver.....	8.9	10.3	0.2	
	8.8	10.3	0	19.1
	8.8	10.7	0	19.5
	8.8	11.0	0	19.8
Aver.....	8.8	10.7	0	
	8.7	10.3	0	19.0
	8.7	10.3	0	19.0
	8.7	10.4	0	19.1
	8.7	11.0	0	19.7
Aver.....	8.7	10.5	0	
	8.6	10.3	0.1	19.0
	8.6	10.7	0	19.3
Aver.....	8.6	10.5	0.1	
	8.5	10.9	0	19.4
	8.5	11.0	0	19.5
	8.5	11.0	0	19.5
	8.5	11.0	0	19.5
	8.5	11.1	0	19.6
Aver.....	8.5	11.0	0	
	8.4	10.6	0	19.0
	8.4	10.8	0	19.2
	8.4	10.8	0	19.2
	8.4	11.0	0	19.4
	8.4	11.0	0	19.4
	8.4	11.4	0	19.8
Aver.....	8.4	10.9	0	

Six Hour Average Samples

TABLE 5—Continued

Arranged According to CO_2

	CO_2	O	CO	Total
		Continued		
	11.0	8.0	0	19.0
	11.0	8.4	0	19.4
	11.0	8.4	0	19.4
	11.0	8.5	0	19.5
	11.0	8.5	0	19.5
	11.0	8.5	0	19.5
	11.0	8.3	0	19.3
	11.0	8.2	0	19.2
Aver.....	11.0	8.4	0	
	11.1	8.2	0	19.3
	11.1	8.2	0	19.3
	11.1	8.5	0	19.6
	11.1	7.9	0	19.0
Aver.....	11.1	8.2		
	11.2	8.0	0	19.2
	11.2	8.0	0	19.2
	11.2	8.0	0	19.2
Aver.....	11.2	8.0	0	
	11.3	8.2	0	19.5
	11.3	8.2	0	19.5
	11.3	7.8	0	19.1
	11.3	7.7	0	19.0
Aver.....	11.3	8.0	0	
	11.4	7.6	0	19.0
	11.4	7.7	0	19.1
	11.4	8.4	0	19.8
Aver.....	11.4	7.9	0	
	11.5	7.8	0	19.3
	11.5	7.8	0	19.3
	11.5	7.5	0	19.0
	11.5	7.5	0	19.0
	11.5	7.9	0	19.4
Aver.....	11.5	7.7	0	
	11.6	7.4	0	19.0
	11.6	7.4	0	19.0
	11.6	8.3	0	19.9
	11.6	7.9	0	19.5
	11.6	7.8	0	19.4
Aver.....	11.6	7.9	0	
	11.7	7.6	0	19.3
	11.7	7.6	0	19.3
	11.7	8.1	0	19.8
	11.7	7.8	0	19.5
	11.7	7.4	0	19.1
Aver.....	11.7	7.7	0	

TABLE 6—Continued

Arranged According to O

	O	CO_2	CO	Total
	8.3	10.0	0	19.3
	8.3	10.7	0	19.0
	8.3	10.7	0	19.0
	8.3	11.0	0	19.3
	8.3	11.6	0	19.9
	8.3	12.2	0.3	20.8
Aver.....	8.3	11.0	0.1	
	8.2	11.0	0	19.2
	8.2	11.0	0	19.2
	8.2	11.1	0	19.3
	8.2	11.1	0	19.3
	8.2	11.3	0	19.5
	8.2	11.3	0	19.5
Aver.....	8.2	11.1	0	
	8.1	11.0	0	19.1
	8.1	11.7	0	19.8
	8.1	11.8	0	19.9
Aver.....	8.1	11.5	0	
	8.0	11.0	0	19.0
	8.0	11.0	0	19.0
	8.0	11.2	0	19.2
	8.0	11.2	0	19.2
	8.0	11.2	0	19.2
	8.0	11.8	0	19.8
Aver.....	8.0	11.2	0	
	7.9	11.1	0	19.0
	7.9	11.5	0	19.4
	7.9	11.6	0	19.5
Aver.....	7.9	11.4	0	
	7.8	11.3	0	19.1
	7.8	11.5	0	19.3
	7.8	11.5	0	19.3
	7.8	11.6	0	19.4
	7.8	11.7	0	19.5
	7.8	11.8	0	19.6
	7.8	12.1	0	19.9
Aver.....	7.8	11.6	0	
	7.7	11.3	0	19.0
	7.7	11.4	0	19.1
	7.7	11.9	0	19.6
	7.7	12.1	0	19.8
	7.7	13.3	0	21.0
Aver.....	7.7	12.0	0	

Six Hour Average Samples

TABLE 5—Continued

Arranged According to CO_2

	CO_2	O	CO	Total
	11.8	7.2	0	19.0
	11.8	7.3	0	19.1
	11.8	7.3	0	19.1
	11.8	8.1	0	19.9
	11.8	8.0	0	19.8
	11.8	7.8	0	19.6
Aver.....	11.8	7.6	0	
	11.9	7.7	0	19.6
	11.9	7.3	0	19.2
Aver.....	11.9	7.5	0	
	†12.0	6.6	0.4	19.0
	12.0	6.9	0.1	19.0
	12.0	7.0	0	19.0
Aver.....	12.0	6.8	0.2	
	12.1	7.8	0	19.9
	12.1	7.6	0	19.7
	12.1	7.1	0	19.8
	12.1	7.2	0	19.2
	12.1	7.2	0	19.3
	12.1	7.3	0	19.4
Aver.....	12.1	7.5	0	
	12.2	7.3	0	19.5
	12.2	6.8	0	19.0
	12.2	6.9	0	19.1
	12.2	7.0	0	19.2
	12.2	7.4	0	19.6
	12.2	7.6	0	19.8
	12.2	7.6	0	19.8
	12.2	8.3	0.3	20.8
Aver.....	12.2	7.4	0	
	12.3	6.6	0.1	19.0
	12.3	7.0	0	19.3
Aver.....	12.3	6.8	0.1	
	12.4	7.2	0	19.6
	12.4	7.2	0	19.6
Aver.....	12.4	7.2	0	
	12.5	7.1	0	19.6
	12.5	6.5	0	19.0
	12.5	7.0	0	19.5
Aver.....	12.5	6.9	0	19.4
	12.6	6.6	0	19.2
	12.6	6.5	0	19.1
	12.6	7.2	0	19.8
Aver.....	12.6	6.8	0	

TABLE 6—Continued

Arranged According to O

	O	CO_2	CO	Total
	7.6	11.4	0	19.0
	7.6	11.7	0	19.3
	7.6	11.7	0	19.3
	7.6	12.1	0	19.7
	7.6	12.2	0	19.8
	7.6	12.2	0	19.8
Aver.....	7.6	11.9	0	
	7.5	11.5	0	19.0
	7.5	11.5	0	19.0
Aver.....	7.5	11.5	0	
	7.4	11.6	0	19.0
	7.4	11.7	0	19.1
	7.4	12.2	0	19.6
Aver.....	7.4	11.8	0	
	7.3	11.8	0	19.1
	7.3	11.8	0	19.1
	7.3	11.9	0	19.2
	7.3	12.1	0	19.4
	7.3	12.2	0	19.5
Aver.....	7.3	12.0	0	
	7.2	11.8	0	19.0
	7.2	12.1	0	19.3
	7.2	12.4	0	19.6
	7.2	12.6	0	19.8
	7.2	12.4	0	19.6
Aver.....	7.2	12.3		
	7.1	12.1	0	19.2
	7.1	12.5	0	19.6
Aver.....	7.1	12.3		
	7.0	12.0	0	19.0
	7.0	12.2	0	19.2
	7.0	12.3	0	19.3
	7.0	12.5	0	19.5
Aver.....	7.0	12.3	0	
	6.9	12.0	0.1	19.0
	6.9	12.2	0	19.1
Aver.....	6.9	12.1	0.1	
	6.8	12.2	0	19.0
	6.8	12.7	0	19.5
Aver.....	6.8	12.5	0	
	6.6	12.0	0.4	19.0
	6.6	12.3	0.1	19.0
	6.6	12.6	0	19.2
Aver.....	6.6	12.3	0.2	

Six Hour Average Samples

TABLE 1—Continued

Arranged According to CO_2

	CO_2	O	CO	Total
	12.7	6.3	0	19.0
	12.7	6.8	0	19.5
Aver.....	12.7	6.6	0	
	12.8	6.2	0	19.0
	12.8	6.2	0	19.0
Aver.....	12.8	6.2	0	
	13.0	6.1	0	19.1
	13.0	6.1	0	19.1
	13.0	6.4	0	19.4
	13.0	6.2	0	19.2
Aver.....	13.0	6.2	0	
	13.1	6.0	0	19.1
	13.2	6.4	0	19.6
	13.2	5.9	0	19.1
	13.2	5.6	0.2	19.0
Aver.....	13.2	6.0	0.1	
	13.3	6.0	0	19.3
	13.3	5.5	0.2	19.0
	13.3	7.7	0	21.0
Aver.....	13.3	6.4	0.1	
	13.5	6.1	0	19.6
	13.6	5.1	0.3	19.0
	13.7	5.5	0	19.2
	13.8	5.2	0	19.0
	13.8	6.0	0	19.8
	13.8	6.0	0	19.8
Aver.....	13.8	5.7	0	

TABLE 1—Continued

Arranged According to O

	O	CO_2	CO	Total
	6.5	12.5	0	19.0
	6.5	12.6	0	19.1
Aver.....	6.5	12.6	0	
	6.4	13.0	0	19.4
	6.4	13.2	0	19.6
Aver.....	6.4	13.1	0	
	6.3	12.7	0	19.0
	6.2	12.8	0	19.0
	6.2	12.8	0	19.0
	6.2	13.0	0	19.2
Aver.....	6.2	12.9	0	
	6.1	13.0	0	19.1
	6.0	13.3	0	19.3
	6.0	12.8	0	18.8
	6.0	12.8	0	18.8
Aver.....	6.0	13.0	0	
	5.9	13.1	0	19.0
	5.9	13.2	0	19.1
Aver.....	5.9	13.2	0	
	5.6	13.2	0.2	19.0
	5.5	13.3	0.2	19.0
	5.5	13.7	0	19.2
Aver.....	5.5	13.5	0.1	
	5.2	13.8	0	19.0
	5.1	13.6	0.3	19.0

Six Hour Average Samples

TABLE 7

Arranged According to CO_2

	CO_2	O	CO	Total
	8.0	10.5	0.1	18.6
	8.0	10.7	0.1	18.8
	8.0	10.1	0.1	18.2
Aver.....	8.0	10.4	0.1	
	8.5	9.9	0.1	18.5
	8.7	9.8	0.1	18.6
	9.0	9.4	0.2	18.6
	9.2	9.4	0.1	18.7
	†9.3	8.7	0.4	18.4
	9.4	8.9	0.2	18.5
	9.5	8.5	0	18.0
	9.6	9.3	0	18.9
	9.6	8.8	0.2	18.6
	9.6	9.3	0	18.9
Aver.....	9.6	9.1	0.1	
	9.7	8.9	0.2	18.8
	†9.7	8.1	0.4	18.2
	9.7	9.0	0.1	18.8
Aver.....	9.7	8.7	0.2	
	†9.8	8.2	0.4	18.4
	9.8	8.8	0.1	18.7
	9.8	9.1	0	18.9
Aver.....	9.8	8.7	0.2	
	9.9	8.9	0.1	18.9
	9.9	8.8	0.1	18.8
Aver.....	9.9	8.9	0.1	
	10.0	8.3	0	18.3
	†10.0	8.1	0.3	18.4
	†10.0	8.1	0.3	18.4
	10.0	8.7	0.1	18.8
	10.0	8.7	0.1	18.8
Aver.....	10.0	8.4	0.2	
	†10.1	7.9	0.4	18.4
	†10.1	7.5	0.5	18.1
	†10.1	7.7	0.4	18.2
Aver.....	10.1	7.7	0.4	

TABLE 8

Arranged According to O

	O	CO_2	CO	Total
	10.7	8.0	0.1	18.8
	10.5	8.0	0.1	18.6
	10.1	8.0	0.1	18.2
	9.9	8.5	0.1	18.5
	9.8	8.7	0.1	18.6
	9.4	9.0	0.2	18.6
	9.4	9.2	0.1	18.7
Aver.....	9.4	9.1	0.2	
	9.3	9.6	0	18.9
	9.3	9.6	0	18.9
Aver.....	9.3	9.6	0	
	9.1	9.8	0	18.9
	9.0	9.7	0.1	18.8
	8.9	9.4	0.2	18.5
	8.9	9.7	0.2	18.8
	8.9	9.9	0.1	18.9
Aver.....	8.9	9.7	0.2	
	8.8	9.6	0.2	18.6
	8.8	9.8	0.1	18.7
	8.8	9.9	0.1	18.8
Aver.....	8.8	9.8	0.1	
	8.7	9.3	0.4	18.4
	8.7	10.0	0.1	18.8
	8.7	10.0	0.1	18.8
Aver.....	8.7	9.8	0.2	
	8.6	10.2	0.1	18.9
	8.5	9.5	0	18.0
	8.4	10.4	0.1	18.9
	8.3	10.5	0.1	18.9
	8.2	9.8	0.4	18.4
	8.2	10.2	0	18.4
	8.2	10.4	0.2	18.8
Aver.....	8.2	10.1	0.2	

Six Hour Average Samples

TABLE 7—Continued

Arranged According to CO_2

	CO_2	O	CO	Total
	10.2	8.6	0.1	18.9
	†10.2	7.8	0.3	18.3
	10.2	8.2	0	18.4
Aver.....	10.2	8.2	0.1	
	10.3	8.0	0.2	18.5
	10.3	8.0	0.2	18.5
Aver.....	10.3	8.0	0.2	
	10.4	8.1	0.2	18.7
	10.4	8.2	0.2	18.8
	10.4	8.4	0.1	18.9
Aver.....	10.4	8.2	0.2	
	10.5	8.0	0.2	18.7
	10.5	7.8	0.2	18.5
	10.5	8.3	0.1	18.9
Aver.....	10.5	8.0	0.2	
	10.6	8.0	0.1	18.7
	10.6	7.7	0.2	18.5
Aver.....	10.6	7.9	0.2	
	†10.7	7.3	0.3	18.3
	†10.7	7.2	0.4	18.3
Aver.....	10.7	7.3	0.4	
	†10.8	7.5	0.3	18.6
	10.8	8.0	0.1	18.9
Aver.....	10.8	7.8	0.2	
	10.9	7.5	0.2	18.6
	10.9	7.2	0.2	18.3
Aver.....	10.9	7.4	0.2	
	11.0	7.5	0.1	18.6
	†11.0	7.1	0.3	18.4
	†11.0	6.5	0.5	18.0
	†11.0	6.5	0.5	18.0
	†11.0	7.3	0.3	18.6
	11.0	7.9	0	18.9
	11.0	7.4	0.2	18.6
	†11.0	7.2	0.3	18.5
	†11.0	7.2	0.3	18.5
	†11.0	6.7	0.4	18.1
	†11.0	7.0	0.4	18.4
	11.0	7.4	0.2	18.6
	11.0	7.8	0.1	18.9
	11.0	7.6	0.2	18.8
	11.0	7.6	0.1	18.7
Aver.....	11.0	7.2	0.3	

TABLE 8—Continued

Arranged According to O

	O	CO_2	CO	Total
	8.1	9.7	0.4	18.2
	8.1	10.0	0.3	18.4
	8.1	10.0	0.3	18.4
	8.1	10.4	0.2	18.7
Aver.....	8.1	10.0	0.3	
	8.0	10.3	0.2	18.5
	8.0	10.3	0.2	18.5
	8.0	10.5	0.2	18.7
	8.0	10.6	0.1	18.7
	8.0	10.8	0.1	18.9
Aver.....	8.0	10.5	0.1	
	7.9	10.1	0.4	18.4
	7.9	11.0	0	18.9
Aver.....	7.9	10.6	0.2	
	7.8	10.2	0.3	18.3
	7.8	10.5	0.2	18.5
	7.8	11.0	0.1	18.9
Aver.....	7.8	10.6	0.2	
	7.7	10.1	0.4	18.2
	7.7	10.6	0.2	18.5
	7.7	11.1	0.1	18.9
Aver.....	7.7	10.6	0.2	
	7.6	11.0	0.2	18.8
	7.6	11.0	0.1	18.7
Aver.....	7.6	11.0	0.2	
	7.5	10.0	0.5	18.1
	7.5	10.8	0.3	18.6
	7.5	10.9	0.2	18.6
	7.5	11.0	0.1	18.6
	7.5	11.1	0.1	18.7
	7.5	11.2	0.2	18.9
	7.5	11.4	0	18.9
Aver.....	7.5	10.9	0.2	
	7.4	11.0	0.2	18.6
	7.4	11.0	0.2	18.6
	7.4	11.4	0.1	18.9
Aver.....	7.4	11.1	0.2	
	7.3	10.7	0.3	18.3
	7.3	11.0	0.3	18.6
	7.3	11.4	0.2	18.9
	7.3	11.5	0.1	18.9
Aver.....	7.3	11.2	0.2	

Six Hour Average Samples

TABLE 7—Continued

Arranged According to CO_2

	CO_2	O	CO	Total
	11.1	7.5	0.1	18.7
	†11.1	7.2	0.3	18.6
	†11.1	7.1	0.3	18.5
	11.1	7.7	0.1	18.9
Aver.....	11.1	7.4	0.2	
	11.2	7.5	0.2	18.9
	†11.2	6.8	0.4	18.4
Aver.....	11.2	7.3	0.3	
	11.3	7.0	0.2	18.5
	†11.3	6.7	0.3	18.3
	11.3	7.0	0.2	18.5
	†11.3	6.9	0.3	18.5
Aver.....	11.3	6.9	0.3	
	11.4	7.4	0.1	18.9
	11.4	7.3	0.2	18.9
	11.4	7.1	0.1	18.6
	11.4	7.5	0 0	18.9
	11.4	6.9	0.2	18.5
	11.4	7.1	0.2	18.7
	11.4	7.2	0.1	18.7
	11.4	7.2	0.1	18.7
	11.4	7.1	0.2	18.7
Aver.....	11.4	7.2	0.1	
	†11.5	6.7	0.3	18.5
	11.5	7.2	0.1	18.8
	†11.5	6.5	0.3	18.3
	11.5	7.2	0.1	18.8
	† 11.5	6.6	0.3	18.4
	11.5	7.2	0.1	8.8
	† 11.5	6.3	0.4	18.2
	11.5	7.1	0.2	18.8
	11.5	7.3	0.1	18 9
	11.5	7.3	0.1	18.9
	†11.5	6.2	0.4	18.1
	†11.5	6.0	0.5	18.0
	†11.5	6.1	0.7	18.3
	†11.5	6.2	0.5	18.2
	11.5	7.2	0.1	18.8
	†11.5	6.5	0.3	18.3
	†11.5	6.1	0.5	18.1
	†11.5	6.6	0.3	18.4
	†11.5	6.3	0.5	18.3
Aver.....	11.5	6.7	0.3	
	11.6	7.1	0.1	18.8
	11.6	6.7	0.2	18.5
	†11.6	6.6	0.3	18.5
Aver.....	11.6	6.8	0.2	

TABLE 2—Continued

Arranged According to O

	O	CO_2	CO	Total
	7.2	10.7	0.4	18.3
	7.2	10.9	0.2	18.3
	7.2	11.0	0.3	18.5
	7.2	11.0	0.3	18.5
	7.2	11.1	0.2	18.6
	7.2	11.4	0.1	18.7
	7.2	11.4	0.1	18.7
	7.2	11.5	0.1	18.8
	7.2	11.5	0.1	18.8
	7.2	11.5	0.1	18.8
	7.2	11.5	0.1	18.8
Aver.....	7.2	11.2	0.2	
	7.1	11.0	0.3	18.4
	7.1	11.1	0.3	18.5
	7.1	11.4	0.1	18.6
	7.1	11.4	0.2	18.7.
	7.1	11.4	0.2	18.7
	7.1	11.5	0.2	18.8
	7.1	11.6	0.1	18.8
Aver.....	7.1	11.3	0.2	
	7.0	11.0	0.4	18.4
	7.0	11.3	0.2	18.5
	7.0	11.3	0.2	18.15
	7.0	11.7	0.1	18.8
	7.0	11.8	0.1	18.9
	7.0	11.8	0.1	18.9
Aver.....	7.0	11.5	0.2	
	6.9	11.3	0.3	18.5
	6.9	11.4	0.2	18.5
	6.9	11.7	0.2	18.8
	6.9	11.8	0.2	18.9
Aver.....	6.9	11.6	0.2	
	6.8	11.2	0.4	18.4
	6.8	12.0	0.1	18.9
Aver.....	6.8	11.6	0.3	
	6.7	11.0	0.4	18.1
	6.7	11.3	0.3	18.3
	6.7	11.5	0.3	18.5
	6.7	11.6	0.2	18.5
	6.7	12.0	0.1	18.8
	6.7	12.0	0.1	18.8
	6.7	12.1	0.1	18.9
Aver.....	6.7	11.6	0.2	

Six Hour Average Samples

TABLE 7—Continued

Arranged According to CO_2

	CO_2	O	CO	Total
	†11.7	6.0	0.4	18.1
	11.7	6.9	0.2	18.8
	†11.7	6.3	0.3	18.3
	11.7	7.0	0.1	18.8
	†11.7	6.4	0.3	18.4
Aver.....	11.7	6.5	0.3	
	11.8	7.0	0.1	18.9
	†11.8	5.4	0.4	17.6
	†11.8	6.2	0.3	18.3
	†11.8	5.9	0.5	18.2
	11.8	6.9	0.2	18.9
	11.8	7.0	0.1	18.9
	†11.8	5.8	0.5	18.1
Aver.....	11.8	6.3	0.3	18.
	†11.9	6.2	0.3	18.4
	†11.9	6.1	0.3	18.3
	†11.9	6.0	0.4	18.3
Aver.....	11.9	6.1	0.3	
	12.0	6.5	0.2	18.7
	†12.0	5.7	0.4	18.1
	†12.0	5.8	0.4	18.2
	12.0	6.7	0.1	18.8
	12.0	6.3	0.2	18.5
	†12.0	6.3	0.3	18.6
	†12.0	6.1	0.3	18.4
	12.0	6.8	0.1	18.9
	12.0	6.6	0.2	18.8
	12.0	6.6	0.1	18.7
	12.0	6.7	0.1	18.8
	12.0	6.6	0.1	18.7
	†12.0	6.1	0.3	18.4
	†12.0	6.2	0.3	18.5
	12.0	6.4	0.2	18.6
	†12.0	5.8	0.4	18.2
	12.0	6.5	0.2	18.7
Aver.....	12.0	6.3	0.2	
	12.1	6.7	0.1	18.9
	†12.1	6.2	0.3	18.6
	12.1	6.4	0.2	18.7
	†12.1	6.1	0.4	18.6
	12.1	6.6	0.1	18.8
	12.1	6.5	0.1	18.7
	†12.1	6.5	0.3	18.9
Aver.....	12.1	6.4	0.2	

TABLE 8—Continued

Arranged According to O

	O	CO_2	CO	Total
	6.6	11.5	0.3	18.4
	6.6	11.5	0.3	18.4
	6.6	11.6	0.3	18.5
	6.6	12.0	0.2	18.8
	6.6	12.0	0.1	18.7
	6.6	12.0	0.1	18.7
	6.6	12.1	0.1	18.8
Aver.....	6.6	11.8	0.2	
	6.5	11.0	0.5	18.0
	6.5	11.0	0.5	18.0
	6.5	11.5	0.3	18.3
	6.5	11.5	0.3	18.3
	6.5	12.0	0.2	18.7
	6.5	12.0	0.2	18.7
	6.5	12.1	0.1	18.7
	6.5	12.1	0.3	18.9
	6.5	12.2	0.1	18.8
	6.5	12.3	0	18.8
Aver.....	6.5	11.8	0.3	
	6.4	11.7	0.3	18.4
	6.4	12.0	0.2	18.6
	6.4	12.1	0.2	18.7
Aver.....	6.4	11.9	0.2	
	6.3	11.5	0.4	18.2
	6.3	11.5	0.5	18.3
	6.3	11.7	0.3	18.3
	6.3	12.0	0.2	18.5
	6.3	12.0	0.3	18.6
Aver.....	6.3	11.7	0.3	
	6.2	11.5	0.4	18.1
	6.2	11.5	0.5	18.2
	6.2	11.8	0.3	18.3
	6.2	11.9	0.3	18.4
	6.2	12.0	0.3	18.5
	6.2	12.1	0.3	18.6
	6.2	12.2	0.2	18.6
	6.2	12.3	0.2	18.7
	6.2	12.3	0.2	18.7
	6.2	12.3	0.1	18.6
	6.2	12.3	0.2	18.7
	6.2	12.4	0.2	18.8
	6.2	12.6	0.1	18.9
Aver.....	6.2	12.1	0.3	

Six Hour Average Samples

TABLE 7—Continued

Arranged According to CO_2

	CO_2	O	CO	Total
	12.2	6.2	0.2	18.6
	12.2	6.5	0.1	18.8
	†12.2	6.1	0.5	18.8
	†12.2	6.1	0.3	18.6
	12.2	5.8	0	18.0
	†12.2	5.6	0.4	18.2
Aver.....	12.2	6.1	0.3	
	†12.3	5.0	0.7	18.0
	†12.3	5.9	0.3	18.5
	12.3	6.0	0.3	18.6
	12.3	6.5	0	18.8
	12.3	6.2	0.2	18.7
	†12.3	6.0	0.3	18.6
	†12.3	5.7	0.3	18.3
	12.3	6.2	0.2	18.7
	12.3	6.2	0.1	18.6
	12.3	6.2	0.2	18.7
Aver.....	12.3	6.0	0.3	
	†12.4	5.2	0.5	18.1
	†12.4	5.5	0.4	18.3
	†12.4	5.5	0.4	18.3
	†12.4	5.4	0.4	18.2
	12.4	6.2	0.2	18.8
	†12.4	5.6	0.3	18.3
Aver.....	12.4	5.6	0.4	
	†12.5	5.1	0.4	18.0
	†12.5	5.0	0.6	18.1
	12.5	6.0	0.2	18.7
	†12.5	5.0	0.7	18.2
Aver.....	12.5	5.3	0.5	
	12.6	6.2	0.1	18.9
	†12.6	5.2	0.4	18.2
	†12.6	5.2	0.4	18.2
	†12.6	6.0	0.3	18.9
	†12.6	5.7	0.3	18.6
Aver.....	12.6	5.7	0.3	
	†12.7	5.1	0.4	18.2
	12.7	5.9	0.1	18.7
	†12.7	5.1	0.4	18.2
	12.7	5.8	0.2	18.7
	†12.7	5.3	0.4	18.4
	12.7	5.7	0.2	18.6
	†12.7	5.3	0.3	18.3
Aver.....	12.7	5.5	0.3	

TABLE 8—Continued

Arranged According to O

	O	CO_2	CO	Total
	6.1	11.5	0.7	18.3
	6.1	11.5	0.5	18.1
	6.1	11.9	0.3	18.3
	6.1	12.0	0.3	18.4
	6.1	12.0	0.3	18.4
	6.1	12.1	0.4	18.6
	6.1	12.2	0.5	18.8
	6.1	12.2	0.3	18.6
	6.1	13.0	0	19.1
	6.1	13.1	0	19.2
	6.1	13.5	0	19.6
Aver.....	6.1	12.3	0.3	
	6.0	11.5	0.5	18.0
	6.0	11.7	0.4	18.1
	6.0	11.9	0.4	18.3
	6.0	12.3	0.3	18.6
	6.0	12.3	0.3	18.6
	6.0	12.5	0.2	18.7
	6.0	12.6	0.3	18.9
	6.0	12.8	0.1	18.9
Aver.....	6.0	12.2	0.3	
	5.9	11.8	0.5	18.2
	5.9	12.3	0.3	18.5
	5.9	12.7	0.1	18.7
Aver.....	5.9	12.3	0.3	
	5.8	11.8	0.5	18.1
	5.8	12.0	0.4	18.2
	5.8	12.0	0.4	18.2
	5.8	12.2	0	18.0
	5.8	12.7	0.2	18.7
	5.8	12.8	0.2	18.8
	5.8	12.9	0.1	18.1
Aver.....	5.8	12.3	0.3	
	5.7	12.0	0.4	18.1
	5.7	12.3	0.3	18.3
	5.7	12.6	0.3	18.6
	5.7	12.7	0.2	18.6
	5.7	12.9	0.2	18.8
Aver.....	5.7	12.5	0.3	
	5.6	12.2	0.4	18.2
	5.6	12.4	0.3	18.3
	5.6	12.8	0.3	18.7
	5.6	12.8	0.3	18.7
	5.6	13.1	0.1	18.8
Aver.....	5.6	12.7	0.3	
	5.5	12.4	0.4	18.3
	5.5	12.4	0.4	18.3
	5.5	13.0	0.3	18.8
Aver.....	5.5	12.6	0.4	

Six Hour Average Samples

TABLE 7—Continued

Arranged According to CO_2

	CO_2	O	CO	Total
	†12.8	5.6	0.3	18.7
	†12.8	5.3	0.3	18.4
	12.8	5.8	0.2	18.8
	†12.8	5.1	0.4	18.3
	†12.8	5.4	0.3	18.5
	12.8	6.0	0.1	18.9
	†12.8	5.6	0.3	18.7
	†12.8	4.6	0.6	18.0
Aver.....	12.8	5.4	0.3	
	12.9	5.8	0.1	18.8
	12.9	5.7	0.2	18.8
Aver.....	12.9	5.8	0.2	
	13.0	5.4	0.2	18.6
	†13.0	5.4	0.3	18.7
	†13.0	5.2	0.3	18.5
	†13.0	5.1	0.4	18.5
	†13.0	5.1	0.4	18.5
	†13.0	5.5	0.3	18.8
	13.0	5.4	0.2	18.6
Aver.....	13.0	5.3	0.3	
	13.1	4.9	0.2	18.2
	13.1	5.4	0.1	18.6
	13.1	5.6	0.1	18.8
	†13.1	4.7	0.5	18.3
	†13.1	5.0	0.4	18.5
Aver.....	13.1	5.1	0.2	
	†13.2	4.0	0.8	18.0
	†13.2	5.0	0.3	18.5
	†13.2	4.5	0.5	18.2
Aver.....	13.2	4.5	0.5	
	†13.3	5.0	0.3	18.6
	†13.3	4.7	0.4	18.4
	13.3	5.3	0.2	18.8
	†13.3	4.9	0.3	18.5
Aver.....	13.3	5.0	0.3	
	13.4	5.2	0.1	18.7
	†13.5	4.2	0.4	18.1
	†13.5	4.8	0.3	18.6
	†13.5	4.9	0.3	18.7
Aver.....	13.5	4.6	0.3	
	†13.6	4.2	0.4	18.2
	†13.6	4.6	0.5	18.7
	†13.6	4.6	0.3	18.5
	†13.6	4.6	0.3	18.5
Aver.....	13.6	4.5	0.4	

TABLE 8—Continued

Arranged According to O

	O	CO_2	CO	Total
	5.4	11.8	0.4	17.6
	5.4	12.4	0.4	18.2
	5.4	12.8	0.3	18.5
	5.4	13.0	0.2	18.6
	5.4	13.0	0.3	18.7
	5.4	13.1	0.1	18.6
Aver.....	5.4	12.7	0.3	
	5.3	12.7	0.4	18.4
	5.3	12.7	0.3	18.3
	5.3	12.8	0.3	18.4
	5.3	13.3	0.2	18.8
Aver.....	5.3	12.9	0.3	
	5.2	12.4	0.5	18.1
	5.2	12.6	0.4	18.2
	5.2	12.6	0.4	18.2
	5.2	13.0	0.3	18.5
	5.2	13.4	0.1	18.7
Aver.....	5.2	12.8	0.3	
	5.1	12.5	0.4	18.0
	5.1	12.7	0.4	18.2
	5.1	12.7	0.4	18.2
	5.1	12.8	0.4	18.4
	5.1	13.0	0.4	18.5
	5.1	13.0	0.4	18.5
Aver.....	5.1	12.8	0.4	
	5.0	12.3	0.7	18.0
	5.0	12.5	0.6	18.1
	5.0	12.5	0.7	18.2
	5.0	13.1	0.4	18.5
	5.0	13.2	0.3	18.5
	5.0	13.3	0.3	18.6
Aver.....	5.0	12.8	0.5	
	4.9	13.1	0.2	18.2
	4.9	13.3	0.3	18.5
	4.9	13.5	0.3	18.7
	4.9	13.8	0.1	18.8
	4.9	13.8	0.2	18.9
	4.9	13.9	0.1	18.9
Aver.....	4.9	13.6	0.2	
	4.8	13.5	0.3	18.6
	4.7	13.1	0.5	18.3
	4.7	13.3	0.4	18.4
Aver.....	4.7	13.2	0.5	

Six Hour Average Samples

TABLE 7—Continued

Arranged According to CO_2

	CO_2	O	CO	Total
	†13.7	4.3	0.3	18.3
	†13.7	4.3	0.4	18.4
	†13.7	4.3	0.4	18.4
Aver.....	13.7	4.3	0.4	
	13.8	4.9	0.1	18.8
	13.8	4.9	0.2	18.9
	†13.8	4.5	0.3	18.6
Aver.....	13.8	4.7	0.2	
	13.9	4.9	0.1	18.9

TABLE 8—Continued

Arranged According to O

	O	CO_2	CO	Total
	4.6	12.8	0.6	18.0
	4.6	13.6	0.5	18.7
	4.6	13.6	0.3	18.5
	4.6	13.6	0.3	18.5
Aver.....	4.6	13.4	0.4	
	4.5	13.2	0.5	18.2
	4.5	13.8	0.3	18.6
Aver.....	4.5	13.5	0.4	
	4.3	13.7	0.4	18.3
	4.3	13.7	0.4	18.4
	4.3	13.7	0.3	18.4
Aver.....	4.3	13.7	0.4	
	4.2	13.5	0.4	18.1
	4.2	13.6	0.4	18.2
Aver.....	4.2	13.6	0.4	
	4.0	13.2	0.8	18.0

Orsat Readings

TABLE 9

Arranged According to CO_2

	CO_2	O	CO	Total
	9.8	8.0	0.3	18.1
	10.0	9.9	0	19.9
	10.2	9.7	0	19.9
	11.0	8.3	0	19.3
	11.0	9.0	0	20.0
Aver.....	11.0	8.7	0	19.7
	11.4	8.0	0	19.4
	11.5	6.1	0.3	17.9
	11.6	7.8	0	19.4
	11.8	6.5	0.2	18.5

TABLE 10

Arranged According to O

	O	CO_2	CO	Total
	9.9	10.0	0	19.9
	9.7	10.2	0	19.9
	9.0	11.0	0	20.0
	8.3	11.0	0	19.3
	8.0	11.4	0	19.4
	8.0	9.8	0.3	18.1
Aver.....	8.0	10.6	0.2	18.8
	7.8	11.6	0	19.4
	7.3	12.0	0	19.3
	7.1	12.5	0	19.6

Orsat Readings

TABLE 9—Continued

Arranged According to CO_2

	CO_2	O	CO	Total
	12.0	7.3	0	19.3
	12.0	7.0	0	19.0
Aver.....	12.0	7.2	0	19.2
	12.3	6.1	0.2	18.6
	12.3	6.7	0	19.0
Aver.....	12.3	6.4	0.1	18.8
	12.5	7.1	0	19.6
	12.7	6.3	0	19.0
	12.8	6.6	0	19.4
	13.0	6.7	0	19.7
	13.0	5.5	0.1	18.6
Aver.....	13.0	6.1	0.1	19.2
	13.2	5.0	0.2	18.4
	13.2	6.2	0	19.4
	13.2	6.8	0	20.0
Aver.....	13.2	6.0	0.1	19.3
	13.4	5.8	0	19.2
	13.5	6.3	0	19.8
	13.5	5.5	0	19.0
	13.5	5.3	0	18.8
	13.5	5.0	0.2	18.7
	13.5	6.2	0	19.7
Aver.....	13.5	5.7	0	19.2
	13.6	5.8	0	19.4
	13.6	4.4	0.3	18.3
	13.6	6.3	0	19.9
Aver.....	13.6	5.5	0.1	19.2
	13.7	6.3	0	20.0
	13.8	6.0	0	19.8
	13.8	6.0	0	19.8
	13.8	6.3	0	20.1
Aver.....	13.8	6.1	0	19.9
	†*14.0	2.1	1.1	17.2
	14.0	4.3	0.2	18.5
	14.0	6.0	0	20.0
	14.0	5.1	0	19.1
Aver.....	14.0	4.4	0.3	18.7
	14.1	5.9	0	20.0
	14.1	5.4	0	19.5
	14.1	4.9	0	19.0
Aver.....	14.1	5.4	0	19.5

TABLE 10—Continued

Arranged According to O

	O	CO_2	CO	Total
	7.0	12.0	0	19.0
	6.8	13.2	0	20 0
	6.7	13.0	0	19.7
	6.7	12.3	0	19.0
Aver.....	6.7	12.7	0	19 4
	6.6	12.8	0	19.4
	6.5	11.8	0.2	18.5
	6.3	13.7	0	20.0
	6.3	12.7	0	19.0
	6.3	13.8	0	20.1
	6.3	13 6	0	19.9
	6.3	13.5	0	19.8
Aver.....	6.3	13.5	0	19.8
	6.2	13.2	0	19.4
	6.2	13.5	0	19.7
Aver.....	6.2	13.4	0	19.6
	6.1	12.3	0.2	18.6
	6.1	11.5	0.3	17.9
Aver.....	6.1	11.9	0.3	18.3
	6.0	13.8	0	19.8
	6.0	14.0	0	20.0
	6.0	13.8	0	19.8
Aver.....	6.0	13.9	0	19.9
	5.9	14.1	0	20.0
	5.8	13.4	0	19.2
	5.8	13.6	0	19.4
Aver.....	5.8	13.5	0	19.3
	5.5	13.0	0.1	18.6
	5.5	13.5	0	19.0
Aver.....	5.5	13.3	0.1	18.8
	5.4	14.1	0	19.5
	5.4	14.4	0	19.8
Aver.....	5.4	14.3	0	19.7
	5.3	13.5	0	18.8
	5.3	14.2	0	19.5
	5.3	14.3	0	19.6
Aver.....	5.3	14.0	0	19.3

Orsat Readings

TABLE 9—Continued

Arranged According to CO_2

	CO_2	O	CO	Total
	†*14.2	2.8	0.7	17.7
	14.2	5.3	0	19.5
Aver.....	14.2	4.1	0.3	18.6
	14.3	5.3	0	19.6
	†*14.3	2.1	0.8	17.2
Aver.....	14.3	3.7	0.4	18.4
	14.4	4.1	0.2	18.7
	14.4	4.2	0.1	18.7
	†*14.4	2.6	0.5	17.5
	14.4	5.4	0	19.8
	†*14.4	3.4	0.5	18.3
	14.4	5.1	0	19.5
Aver.....	14.4	4.1	0.2	18.8
	14.5	5.1	0	19.6
	14.5	5.1	0	19.6
	†*14.5	2.0	0.7	17.2
	14.5	4.3	0.1	18.9
	14.5	2.0	1.0	17.5
Aver.....	14.5	3.7	0.4	18.6
	14.6	2.3	0.9	17.8
	†*14.6	3.0	0.5	18.1
	14.6	2.0	1.0	17.6
	14.6	1.7	0.8	17.1
Aver	14.6	2.3	0.8	17.7
	†*14.7	1.6	0.9	17.2
	†*14.7	2.0	0.6	17.3
	†*14.7	1.6	0.9	17.2
	†*14.7	2.7	0.7	18.1
	14.7	4.0	0.1	18.8
Aver.....	14.7	2.4	0.6	17.7
	†*14.8	2.9	0.5	18.2
	14.8	3.1	0.3	18.2
	†*14.8	1.2	1.1	17.1
	14.8	4.4	0	19.2
	14.8	4.4	0	19.2
Aver.....	14.8	3.2	0.4	18.4
	†*15.0	2.2	0.6	17.8
	†*15.0	2.2	0.5	17.7
	15.0	3.3	0.2	18.5
	15.0	3.0	0.3	18.3

Continued on next page

TABLE 10—Continued

Arranged According to O

	O	CO_2	CO	Total
	5.1	14.4	0	19.5
	5.1	14.5	0	19.6
	5.1	14.0	0	19.1
	5.1	14.5	0	19.6
Aver.....	5.1	14.4	0	19.5
	5.0	13.5	0.2	18.7
	5.0	13.2	0.2	18.4
Aver.....	5.0	13.4	0.2	18.6
	4.9	14.1	0	19.0
	4.7	15.1	0	19.8
	4.4	13.6	0.3	18.3
	4.4	14.8	0	19.2
	4.4	14.8	0	19.2
Aver.....	4.4	14.4	0.1	18.9
	4.3	14.5	0.1	18.9
	4.3	15.5	0	19.8
	4.3	14.0	0.2	18.5
Aver.....	4.3	14.7	0.1	19.1
	4.2	15.3	0	19.5
	4.2	14.4	0.1	18.7
Aver.....	4.2	14.9	0	19.1
	4.1	15.0	0	19.1
	4.1	14.4	0.2	18.7
Aver.....	4.1	14.7	0.1	18.9
	4.0	15.5	0	19.5
	4.0	14.7	0.1	18.8
	4.0	15.5	0	19.5
Aver.....	4.0	15.2	0	19.3
	3.8	15.0	0	18.8
	3.8	15.2	0	19.0
Aver.....	3.8	15.1	0	18.9
	3.7	16.3	0	20.0
	3.7	15.8	0	19.5
Aver.....	3.7	16.1	0	19.8
	3.6	15.5	0	19.1
	3.5	16.0	0	19.5
	3.5	16.1	0	19.6
	3.5	15.4	0	18.0
Aver.....	3.5	15.8	0	19.3

Orsat Readings

TABLE 9—Continued

Arranged According to CO_2

	CO_2	O	CO	Total
		Continued		
	†*15.0	1.3	0.8	17.1
	15.0	4.1	0	19.1
	†*15.0	1.8	0.9	17.7
	†*15.0	2.2	0.8	18.0
	15.0	3.5	0.2	18.7
	†*15.0	1.8	0.5	17.3
	†*15.0	1.2	0.8	17.0
	†*15.0	2.2	0.5	17.7
	†*15.0	1.8	0.6	17.4
	15.0	3.8	0	18.8
Aver.....	15.0	2.5	0.5	17.9
	15.1	4.7	0	18.9
	†*15.1	2.4	0.5	18.0
	15.1	4.2	0	19.3
	15.1	2.4	0.5	18.0
Aver.....	15.1	3.5	0.3	18.8
	†*15.2	2.1	0.5	17.8
	†*15.2	2.5	0.4	18.1
	15.2	3.8	0	19.0
Aver.....	15.2	2.8	0.3	18.3
	†*15.2	2.4	0.4	18.1
	†*15.3	1.7	0.6	17.6
	†*13.3	1.6	0.5	17.4
	15.3	4.2	0	19.5
Aver.....	15.3	2.5	0.4	18.2
	15.4	3.5	0	18.9
	†*15.4	2.2	0.5	18.1
	15.4	2.9	0.3	18.6
Aver.....	15.4	2.9	0.3	18.5
	15.5	4.0	0	19.5
	15.5	4.3	0	19.8
	15.5	3.0	0.2	18.7
	15.5	4.0	0	19.5
	†*15.5	1.0	0.8	17.3
	15.5	3.6	0	19.1
Aver.....	15.5	3.3	0.2	19.0
	†*15.6	2.1	0.5	18.2
	15.6	2.6	0.3	18.5
	†*15.6	1.9	0.4	17.9
	†*15.6	1.4	0.5	17.5
Aver.....	15.6	2.0	0.4	18.0

TABLE 10—Continued

Arranged According to O

	O	CO_2	CO	Total
	3.4	14.4	0.5	18.5
	3.3	15.9	0	19.2
	3.3	15.0	0.2	18.5
Aver.....	3.3	15.5	0.1	18.9
	3.2	16.0	0	19.2
	3.1	16.3	0	19.4
	3.1	14.8	0.3	18.2
Aver.....	3.1	15.6	0.2	18.8
	3.0	15.0	0.3	18.3
	3.0	15.8	0.8	18.8
	3.0	15.5	0.2	18.7
	3.0	14.6	0.5	18.1
Aver.....	3.0	15.2	0.3	18.5
	2.9	15.4	0.3	18.6
	2.9	14.8	0.5	18.2
Aver.....	2.9	15.1	0.4	18.4
	2.8	14.2	0.7	17.7
	2.7	14.7	0.7	18.1
	2.6	15.6	0.3	18.5
	2.6	14.4	0.5	17.5
	2.6	16.5	0	19.1
Aver.....	2.6	15.5	0.3	18.4
	2.5	16.6	0	19.1
	2.5	15.2	0.4	18.1
Aver.....	2.5	15.9	0.2	18.6
	2.4	15.1	0.5	18.0
	2.4	15.1	0.4	18.0
	2.4	15.3	0.4	18.1
Aver.....	2.4	16.2	0.5	18.0
	2.3	15.7	0.3	18.3
	2.3	14.6	0.9	17.8
Aver.....	2.3	15.2	0.6	18.1
	2.2	15.0	0.6	17.8
	2.2	15.0	0.8	18.0
	2.2	15.4	0.5	18.1
	2.2	15.0	0.5	17.7
	2.2	15.0	0.5	17.7
Aver.....	2.2	15.1	0.6	17.9
	2.1	15.2	0.5	17.8
	2.1	14.0	1.1	17.2
	2.1	14.3	0.8	17.2
	2.1	15.6	0.5	18.2
Aver.....	2.1	14.8	0.7	17.6

ORSAT READINGS

TABLE 9—Continued

ARRANGED ACCORDING TO CO_2

	CO_2	O	CO	Total
	15.7	2.3	0.3	18.3
	15.7	2.0	0.3	18.0
Aver.....	15.7	2.2	0.3	18.2
	†*15.8	1.0	0.5	17.4
	15.8	3.7	0.6	19.5
	15.8	3.0	0	18.8
Aver.....	15.8	2.6	0.2	18.6
	15.9	3.3	0	19.2
	16.0	3.5	0	19.5
	16.0	3.2	0	19.2
	†*16.0	1.1	0.8	17.9
	†*16.0	1.5	0.4	17.9
Aver.....	16.0	2.3	0.3	18.6
	16.1	3.5	0	19.6
	16.2	2.0	0.2	18.4
	16.3	3.7	0	20.0
	16.3	3.1	0	19.4
Aver.....	16.3	3.4	0	19.7
	16.4	1.3	0.3	18.0
	16.4	1.6	0.2	18.2
Aver.....	16.4	1.5	0.2	18.1
	†*16.5	1.2	0.4	18.1
	16.5	1.8	0.2	18.5
	16.5	2.6	0	19.1
Aver.....	16.5	1.9	0.2	18.6
	16.6	2.5	0	19.1

TABLE 10—Continued

ARRANGED ACCORDING TO O

	O	CO_2	CO	Total
	2.0	16.2	0.2	18.4
	2.0	14.6	1.0	17.6
	2.0	14.7	0.6	17.3
	2.0	14.5	1.0	17.5
	2.0	14.5	0.7	17.2
	2.0	15.7	0.3	18.0
Aver.....	2.0	15.0	0.6	17.7
	1.9	15.6	0.4	17.9
	1.8	15.0	0.5	17.3
	1.8	15.0	0.6	17.4
	1.8	15.0	0.9	17.7
	1.8	16.5	0.2	18.5
Aver.....	1.8	15.4	0.6	17.7
	1.7	15.3	0.6	17.6
	1.7	14.6	0.8	17.1
Aver.....	1.7	15.0	0.7	17.4
	1.6	16.4	0.2	18.2
	1.6	14.7	0.9	17.2
	1.6	15.3	0.5	17.4
	1.6	14.7	0.9	17.2
Aver.....	1.6	15.3	0.6	17.5
	1.5	16.0	0.4	17.9
	1.4	15.6	0.5	17.5
	1.3	15.0	0.8	17.1
	1.3	16.4	0.3	18.0
Aver.....	1.3	15.7	0.6	17.6
	1.2	16.5	0.4	18.1
	1.2	15.0	0.8	17.0
	1.2	14.8	1.1	17.1
Aver.....	1.2	15.4	0.8	17.4
	1.1	16.0	0.8	17.9
	1.0	15.8	0.6	17.4
	1.0	15.5	0.8	17.3
Aver.....	1.0	15.7	0.7	17.4

APPENDIX NO. 2

CALCULATION OF HEAT CARRIED OFF BY THE FLUE GAS

NOTATION

A = weight of air consumed in burning a weight of fuel containing 1 lb. of carbon

A_c = theoretical weight of air required to burn 1 lb. of carbon

A_h = theoretical weight of air required to burn 1 lb. of hydrogen

A_e = weight of air in excess of that theoretically required to burn a weight of fuel containing 1 lb. of carbon

F_c = weight of fixed carbon per lb. of fuel

V_c = weight of volatile combustible per lb. of fuel

$R = \frac{V_c}{F_c}$ = ratio of volatile combustible to fixed carbon in fuel

$R' = \frac{H + C_xH_y}{C}$ = ratio of the volatile combustible to the total carbon in liquid or gaseous fuel

$H_a = H - \frac{O}{8}$ = weight of available hydrogen in fuel per lb. of carbon

O = weight of oxygen in fuel per lb. of carbon

$W_h = O + \frac{O}{8}$ = weight of water of hydration in fuel per lb. of carbon

W_m = weight of water (moisture) in fuel per lb. of carbon

P_a = percentage of moisture contained in air

P = percentage of CO_2 contained in flue gas

P_c = percentage of CO contained in flue gas

P_{vc} = percentage of volatile combustible contained in flue gas, i.e., H and C_xH_y

P_e = percentage of excess of air

L = B.t.u. loss due to sensible heat in flue gas per lb. of carbon in fuel when burned with dry air

L_c = B.t.u. loss due to fuel value of CO in flue gas per lb. of carbon in fuel when burned with dry air

L_{vc} = B.t.u. loss due to fuel value of $(H + C_xH_y)$ in flue gas per lb. of carbon in fuel when burned with dry air

L_v = B.t.u. loss due to moisture in air per lb. of carbon

L_m = B.t.u. loss due to moisture in fuel per lb. of carbon

L_h = B.t.u. loss due to hydrated moisture in fuel

L_t = B.t.u. loss due to all of the above losses per lb. of carbon in fuel burned

T = temperature of flue gas on leaving boiler
t = temperature of air in boiler house
S = specific heat of dry flue gas
S_w = specific heat of water vapor

Pure air contains	by weight	by volume
Oxygen (O_2)	23 %	21 %
Nitrogen (N_2)	77 %	79 %

Weights (lb.) per cu. ft. at 62 deg.fahr.		Specific Heats (S)	
Dry air	0.0761	Air	0.237
N_2	0.0738	N_2	0.244
CO	0.0735	O_2	0.217
CO_2	0.1159	CO_2	0.217
H_2O	0.0472	CO	0.247
		Average	0.23

Specific heat (S_w) of H_2O = 0.48
Atomic weight of H = 1
Atomic weight of C = 12
Atomic weight of O = 16

COMPLETE COMBUSTION WITH THEORETICAL AMOUNT OF AIR

47 One pound of carbon theoretically requires 11.6 lb. or 152 cu. ft. of air for complete combustion, forming 12.6 lb. of combustion product. According to Avogadro's law a molecule of CO_2 occupies the same space as a molecule of O_2, hence the combustion product consists of 21% CO_2 and 79% N_2 by volume. Thus, when burning carbon with its theoretically required volume of air $P = 21\%$, which is the maximum amount obtainable, and the heat carried off by the combustion products will be the minimum, viz: $(A_c + 1) \times (T - t)\, S$. Since $A_c = 11.6$ per lb. of carbon we have

$$L = 12.6\ (T - t)\ S \qquad [1a]$$

Substituting the value of S and reducing, we have

$$L = 2.9\ (T - t) \qquad [1]$$

COMPLETE COMBUSTION OF CARBON WITH AN EXCESS OF AIR

48 When carbon is burned with an excess of air (A_e), which by volume equals $\frac{A_e}{0.0761}$ cu. ft., then

$$P = \frac{21 \times 152}{152 + \frac{A_e}{0.0761}}$$

from which we get $A_e = \frac{21 \times 11.6}{P} - 11.6$. The total weight of air

$A = A_c + A_e$. Substituting the values of A_c and A_e, we have

$$A = \frac{21 \times 11.6}{P}$$

$$L' = (1 + A) \times (T - t)\, S \quad \ldots\ldots [2a]$$

Substituting the values for A and S and reducing to the lowest terms we have

$$L' = \left(0.23 + \frac{56}{P}\right) \times (T - t) \quad \ldots\ldots [2]$$

The percentage of excess of air for carbon will be

$$P_e = \frac{A_e \times 100}{A}.$$ Substituting the values of A and A_e and reducing, we have $P_e = \frac{2100}{P} - 100$.

INCOMPLETE COMBUSTION OF CARBON

49 If combustion is incomplete, i.e., if some of the carbon passes off with the combustion product as CO, an additional loss is sustained. Since a pound of carbon burned to CO develops only 4350 B.t.u. instead of 14,500 when burned to CO_2, we have a loss of 14,500 − 4350 = 10,150 B.t.u. for every pound of carbon which passes off as CO.

50 The burning of carbon to CO requires only one-half the weight of air required for CO_2; the presence of CO in the flue gas must, therefore, tend to make the value of A too great; but since P_c is always relatively very small, the presence of CO will not appreciably affect the value of L.

LOSS DUE TO CO IN FLUE GAS

51 When the percentage of CO (P_c) is known, the heat loss due to its presence (L_c) is easily determined. The weight of carbon in a molecule of CO is the same as in a molecule of CO_2 and it follows from Avogadro's law that the weight of carbon burned to CO is to that burned to CO_2 as the per cent of CO is to the per cent of CO_2 contained in the combustion product. Thus, letting X = the weight of carbon burned to CO, we have $\frac{X}{1 - X} = \frac{P_c}{P}$ from which we get $X = \frac{P_c}{P + P_c}$ = carbon burned to CO per unit of carbon contained in the fuel. Since CO burned to CO_2 per unit of carbon develops 10,150 B.t.u., we have $L_c = 10{,}150 \frac{P_c}{P + P_c}$. For the total loss when dry carbon is burned with dry air, we have $L_t = L' + L_c$ ..... [3a]

Substituting the values of L' and L_c, we have

$$L_t = \left(0.23 + \frac{56}{P}\right) \times (T - t) + 10{,}150 \frac{P_c}{P + P_c} \quad \ldots\ldots [3]$$

EFFECT OF MOISTURE IN FUEL AND AIR

52 Thus far we have considered both fuel and air to be dry, a condition which never exists in practice. The humidity in the air may vary from a fraction of one per cent to several per cent and commercial fuel is never dry. Coke or charcoal, as well as mineral coal, may contain 10% or more of moisture.

53 Atmospheric moisture exerts a chilling effect on the fire because of its high specific heat and because at least part of it will be decomposed. But since under normal conditions the hydrogen which was set free by decomposition will reunite with the oxygen from the air in the combustion chamber and will evolve as much heat there as was absorbed in the fuel bed in setting it free, there results no heat loss due to this double reaction. It will be necessary, therefore, to consider only the sensible heat carried off by moisture contained in the air, hence

$$L_v = \left(A \frac{P_a}{100}\right) \times (T - t)\, S_v$$

Substituting the values of A and S_v and reducing to lowest terms, we have

$$L_v = \frac{1.17\, P_a}{P} \times (T - t)$$

54 Moisture in fuel (W_m) exists in the form of water which must first be heated to 212 deg. and then evaporated, the vapor passing off at the temperature of the flue gas. Since the latent heat of evaporation is 966 B.t.u. and the specific heat of water vapor is 0.48, we have $L_m = (212 - t + 966)\, M + (T - 212)\, 0.48\, M$. Hence, when burning wet fuel with natural air, we get for the total loss

$$L_t = L' + L_c + L_v + L_m \quad \text{.....[4a]}$$

Substituting values and reducing to lowest terms, we get

$$L_t = \frac{(56 + 1.17\, P_a) \times (T - t)}{P} + \frac{10{,}150\, P_c}{P + P_c}$$

$$+ 0.23 \times [(T - t) + 110 - t + 48\, T + 966]\, M \quad \text{.....[4]}$$

CALCULATION OF HEAT LOST IN THE FLUE GAS WHEN HYDROGEN FORMS AN APPRECIABLE PART OF THE FUEL

55 In the chemical reaction which constitutes the combustion of hydrogen, 8 lb. of oxygen and 1 lb. of hydrogen unite to form 9 lb. of water vapor. This requires 34.8 lb. or 457 cu. ft. of air and results in 35.78 lb. of combustion product. In commercial flue-gas analysis no account is taken of the moisture, hence nitrogen only is determined in the combustion product from hydrogen. The burning of 1 lb. of hydrogen with the theoretically required volume of air therefore results in 361 cu. ft. of nitrogen.

56 If the fuel consists of carbon and hydrogen and is burned with the theoretically required air, we have $P = \frac{152\ C \times 21}{152\ C + 361\ H_a}$. Placing $C = 1$ and reducing volume to weight, $P = \frac{11.6 \times 21}{11.6 + 26.7\ H_a}$. If there is excess air, we have $P = \frac{11.6 \times 21}{11.6 + 26.7\ H_a + A_e}$, from which we get $A_e = \frac{11.6 \times 21}{P} - 11.6 - 26.7\ H_a$ and $A = A_c + A_h + A_e = \frac{11.6 \times 21}{P} + 8.1\ H_a$. $L'' = (A + 1) \times (T - t)\ S + 9\ H_a\ (T - t)\ S_w$. Substituting for A, A_e, S and S_w their values and reducing to lowest terms we have

$$L'' = (0.23 + \frac{56}{P} + 6.2\ H_a) \times (T - t)$$

57 This formula will give correct results for anhydrous fuel containing hydrogen when burned with dry air, assuming complete combustion. When burning pure carbon fuel (coke or charcoal), CO is the only fuel constituent contained in the combustion product, but as soon as the fuel contains an appreciable amount of volatile combustible, both hydrogen and hydrocarbons may appear in the fuel gas. The loss equation when burning dry hydrocarbon fuel with natural air becomes

$$L_t = L'' + L_v + L_c + L_{vc} \quad \text{.....[5a]}$$

The last term of this equation will increase in importance with the volatile combustible (V_c) in the fuel. It will be zero with coke and charcoal, insignificant with anthracite, it may approach the value of L_c in bituminous, and will probably equal or even surpass it in liquid and gaseous hydrocarbon fuels.

58 Because of the difficulty encountered in determining the percentage of H and C_xH_y in flue gas, little or nothing is known as to their quantitive relation to CO_2 and CO. It may be assumed, however, with a considerable degree of certainty that if a fuel is burned to such a degree of completeness that no measurable amount of CO is found in the flue gas, H and C_xH_y will also be absent. It would even seem probable, and therefore reasonable to assume, at least until the contrary has been demonstrated, that in the combustion of any hydrocarbon fuel the absence of CO may be considered as evidence of complete combustion. But when CO is present in the flue gas from hydrocarbon fuel, H and C_xH_y constitutents must also be suspected and should be included in any formula which pretends to express the total loss of heat and fuel through the chimney, even though it is not practicable to determine these constituents in the daily flue-gas analyses.

59 It is reasonable to suppose that the tendency for H and C_xH_y to be associated with CO when combustion is incomplete will increase with the volatile combustible (V_c) contained in the fuel. We may, therefore, assume that the percentage of H and C_xH_y in the flue gas is to the CO as the percentage of volatile combustible in the coal is to the fixed carbon. Representing the latter ratio by R, we have $R = \frac{P_{vc}}{P_c}$, from which we get $P_{vc} = P_cR$.

60 For liquid and gaseous fuels containing little or no fixed carbon we will probably not be far wrong if we assume this ratio to be equal to the ratio of the hydrogen and hydrocarbon combustibles to the total carbon content of the fuel, i.e.,

$$R' = \frac{H + C_x H_y}{C} = \frac{P_{vc}}{P_c}. \quad \text{Hence } P_{vc} = P_c R'$$

61 Then if we let the heat value of the hydrogen and hydrocarbon combustibles in the flue gas equal that of CO, volume for volume, we have $L_{vc} = 10{,}150\, P_c R$.

$$L_t = L'' + L_v + L_c + L_{vc} \quad \ldots\ldots [5a]$$

Substituting the values previously determined and reducing to lowest terms, we have

$$L_t = \frac{(56 + 1.17\ P_a) \times (T - t)}{P} + \frac{10{,}150\ (P_c + P_c R')}{P + P_c} + (0.23 + 6\, H_a) \times (T - t) \quad \ldots\ldots [5]$$

62 There is no experimental data at hand to prove or disprove the substantial correctness of the above relation. All that can be said in its favor is that it would appear reasonable that such relation exists between the CO and the other combustible constituents contained in flue gas. Equation [5] represents the total heat loss up the stack when burning liquid or gaseous fuel free from moisture.

WATER OF HYDRATION

63 All mineral coals contain water in two forms: moisture (W_m), i.e., water which can be driven off by drying at about 212 deg.; and water of hydration (W_h), which passes off at much higher temperatures with the volatile combustible matter, the estimation of which is ordinarily but wrongly included in the latter. True moisture (W_m) has already been considered.

64 If we know the weight of oxygen contained in the coal, the water of hydration is determined by the equation $W_h = O + \frac{O}{8}$, i.e., 1 lb. of oxygen combines with $\frac{1}{8}$ lb. of hydrogen and forms $\frac{9}{8}$ lb. of water. We therefore have $L_h = 1.125 \times O \times (T - t)\, S_v = 0.54 \times O \times (T - t)$. The total sensible and potential heat carried off by the flue gas from bituminous coal therefore becomes

$$L_t = L'' + L_v + L_c + L_{vc} + L_m + L_h \quad \ldots\ldots [6a]$$

Substituting and arranging terms, we have

$$L_t = \frac{(56 + 1.17\ P_a) \times (T - t)}{P} + \frac{10{,}150\ (P_c + P_c R)}{P + P_c} + (0.23 + 0.54 \times O) \times (T - t) + (110t + 0.48T + 966)\, M + 0.23 \quad \ldots\ldots [6]$$

From these heat loss equations we see that the loss of heat by way of the chimney is the sum of a number of distinct components; and that the loss occurs in two ways, (*a*) sensible heat and (*b*) unconsumed combustible.

65 When burning carbon fuel the loss components are

$$L_t = L + L_c + L_v + L_m \quad \ldots\ldots [4a]$$

The values of thsee components are

$$L' = (0.23 + \frac{56}{P} \times (T - t)$$

$$L_v = \frac{1.17\ P_a}{P} \times (T - t)$$

$$L_c = \frac{10{,}150\ P_c}{P + P_c}$$

$$L_m = (110 - t + 0.48\ T + 966)\ M$$

When burning mineral coal the loss components are

$$L_t = L' + L_v + L_c + L_{vc} + L_m + L_h \quad \ldots\ldots\ldots\ldots\ldots\ldots [6a]$$

The values of these components are

$$L'' = (0.23 + \frac{56}{P} + 6.2\ H_a) \times (T - t)$$

$$L_v = \frac{1.17\ P_a}{P} \times (T - t)$$

$$L_c = 10{,}150 - \frac{P_c}{P + P_c}$$

$$L_{vc} = 10{,}150 \frac{P_c R}{P + P_c}$$

$$L_m = (110 - t + 0.48\ T + 966)\ M$$

$$L_h = 0.54 \times O \times (T - t)$$

66 From the values of the components of equation [4a] we see that the loss due to the first three decreases directly as the CO_2 increases and the loss due to the first, second and fourth increases directly with the temperature of the escaping flue gases. Similarly, we see from the values of the components of equation [6a] that the loss decreases as the CO_2 increases in the first four components, and increases with the flue-gas temperature in the first, second, fifth and sixth.

NOTES ON A HEAVY-DUTY GAS PRODUCER

By Nisbet Latta, Milwaukee, Wis.
Junior Member

The heavy-duty gas engine may be said to have been developed in the United States to a reasonable degree of commercial acceptability. The adoption of this engine by the various steel companies, the economical operation of the engines installed and the general degree of reliability obtained has established it upon a firm foundation as a recognized prime mover in this industry. The general adoption of the gas engine, however, and its refinement, with regard to those obstacles which yet remain and which can only be eliminated through a prolonged process of evolution, must depend upon a wider field. Such expansion of field depends upon a supply of fuel suitable in uniformity and economy for use in the internal combustion engine.

2 Generally speaking, the heavy-duty gas engine has been confined to those operations where either natural gas or blast-furnace gas was available; hence, before they can be generally adopted, some method for the economical manufacture of a satisfactory gas in large volumes must be assured. The difficulties of such manufacture have been many, and a few of them are herewith recited.

3 The initial introduction of gas producers into the United States was unfortunate and the failure of the greater number of the first installations cast upon the producer a cloud of discredit which has never been removed entirely from the public mind. This failure was due, in most part, to the wrong hypothysis that because this apparatus has been successful in England and on the Continent it must necessarily be so in this country. The fallacy of this idea was due to the single variable, the nature of the fuel used. The easily fusible ash contained in the English and German coals permitted a high rate of combustion, averaging 18 lb. to 20 lb. per sq. ft. of cross section. When operation at this rate was attempted here, it was found to be impossible to control the fire bed, the resulting temperature being such as to

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flux and finally fuse the ash and to produce other conditions inconsistent with satisfactory operation.

4 To avoid this condition of affairs, the rating of American producers has steadily been decreased until the best practice now averages from 8 lb. to 9 lb. of fuel gasified per square foot of grate surface. This change has rectified to a great extent the difficulties met with in the introduction of the apparatus upon this side of the Atlantic. The success of such installations as the Tait process at the John Thompson Press Company and the Loomis-Pettibone plant of the Milwaukee Northern Railway Company are examples of the development of the American producers properly engineered. Such plants, however, are relatively small in size, while the heavy-duty gas engine for power purposes is essentially an apparatus of large capacity and demand. The average gas producer in common practice today does not exceed 500 h.p. in size.

5 Even at this size, and invariably beyond it, mechanical troubles occur which are difficult if not impossible to remedy. For instance in producers of great diameter there are different heat zones or strata, due to the difference of temperature between the center of the apparatus and the sides, which are cooled to some extent by radiation. Moreover, the increase in diameter causes almost insurmountable difficulties in stoking and prevents the possibility of maintaining the fuel bed at a high efficiency.

6 Again, the labor of cleaning is immeasurably increased. This condition of affairs is peculiarly emphasized in the case of caking or coking coals containing a high percentage of fines (coal under ¼-in. mesh) which tend to form a homogeneous mass, packing or caking the bed. Coals such as are found in Kansas or Illinois, particularly the former, make operation difficult under these conditions. The commercial limit of fines in the case of pressure producers seems to be about 15 per cent for caking coal and about 40 per cent for free-burning coal. With the latter 65 per cent of fines is the maximum obtained in commercial operation. In some coals the ash fuses at an early stage of combustion, while others form a densely packed or "mucky" bed, almost like molten asphalt.

7 The difficulty and labor of operation under these conditions has hitherto been met by some expedient such as mechanical agitation. The well-known Hughes producer, an instance of this type, has a "walking-beam" poker which periodically punctures and stirs the fuel bed. Other mechanical methods have involved the rotation of

one or more zones of the producer so as to turn or twist separate sections of the fire bed upon its own axis. Sections of the producer have also been caused to oscillate and such arrangements as shaking or rotative grates have been long and commonly used. Another method of agitation, perhaps more unique, is in successful practice in certain types of the Loomis-Pettibone apparatus, wherein compressed gas is used as the agitating medium. A certain volume of gas is compressed into a small storage tank or receiver, from which a gas-opening valve suddenly admits it under the fuel bed of the producer, the result being to lift the bed and redispose it, to blow out the ashes from the interstices of the fuel, and to refresh and make more active the fuel surface. This method, especially within a producer of moderate size, can unquestionably be commended.

8 Nevertheless, the fact remains that although the medium-sized producer, of say 750 h.p., has been developed with a reasonable degree of commercial success, we have not as yet obtained a gas-producing apparatus which may be said to be a consort for the heavy-duty steel-plant type gas engine of 3000 to 5000 horsepower.

9 The argument has been presented that the solution of the matter consists in the use of a number of producer units and their connection in batteries or multiples, analogy being made with steam boiler practice. The installation of a 2000-h.p. steam turbine would not necessitate the construction of a 2000-h.p. steam boiler, but more likely four 500-h.p. units or even three 750-h.p. units, allowing a safe factor for easy steaming. This analogy fails by reason of the essential difference in the character of the service performed. For instance, within certain limits the question of boiler operation means merely the delivery of steam at a certain pressure, the pressure regulation between the boilers being a matter which is comparatively simple. The efficient operation of a gas engine, however necessitates the delivery not only of a continuous supply of gas, but gas of uniform composition. This condition of affairs is made even more complex where the load is variable, and the process of synchronizing and maintaining in synchronism the multiplicity of producer units is more difficult in practice than it would seem theoretically. Again, there are inherent industrial disadvantages such as relatively high labor costs, increased cost of maintenance, and complex coal and ash-handling devices.

10 The foregoing summary will briefly explain the reason for starting about a year ago, a series of experiments on a large-sized mechanically-operated producer. Although incomplete as yet, they

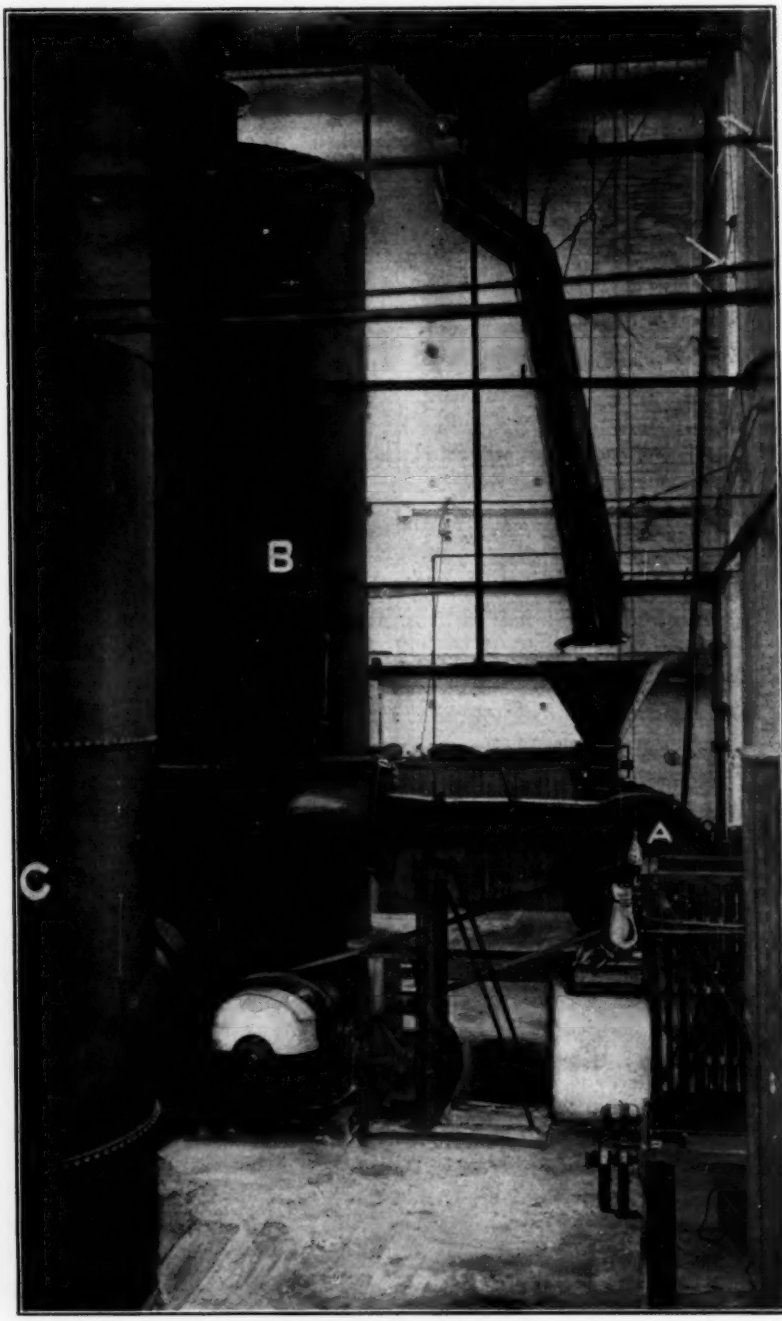

FIG. 1 3000 H.P. HIRT PRODUCER AND EQUIPMENT

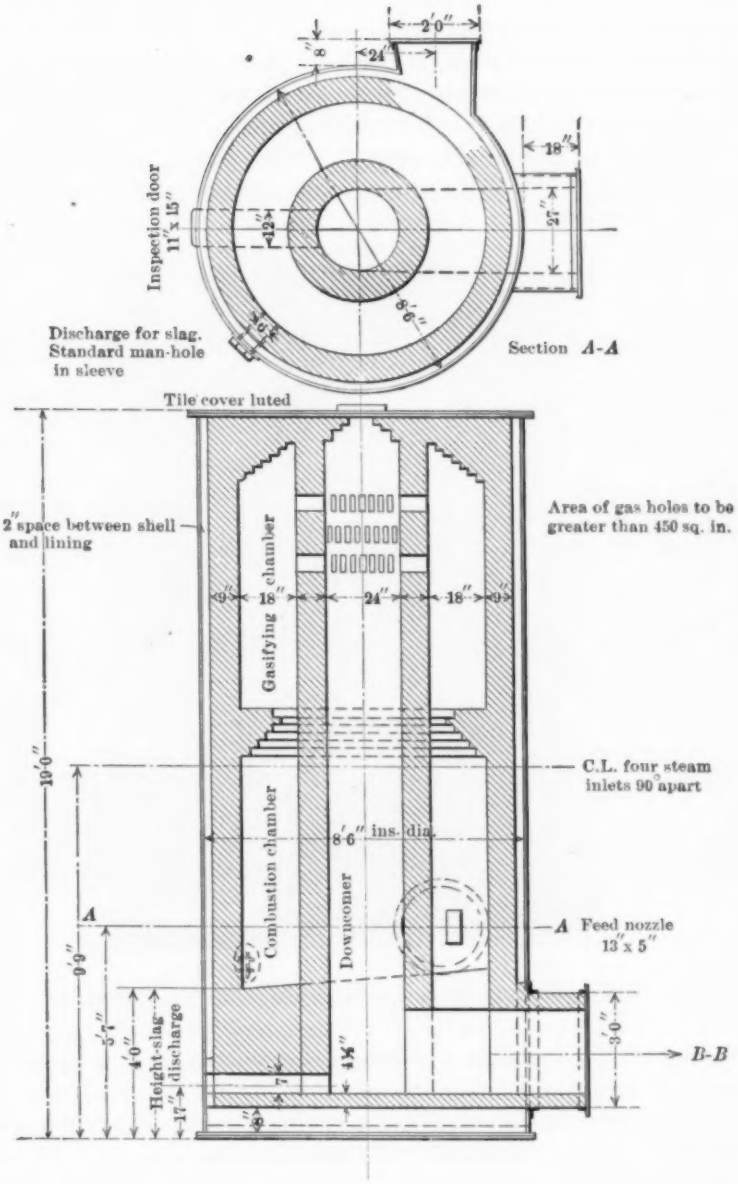

FIG. 2 VERTICAL SECTION OF HIRT-PRODUCER

tend to show the possibilities of the manufacture of gas on a large scale at a low cost.

11 The apparatus selected was of the pulverized-fuel type, the one herein described having originally been designed by L. H. Hirt. This type of producer is hardly an innovation, having been in operaton in France for a number of years. The French producer was the work of Georges Marconnet, a French engineer. This apparatus is

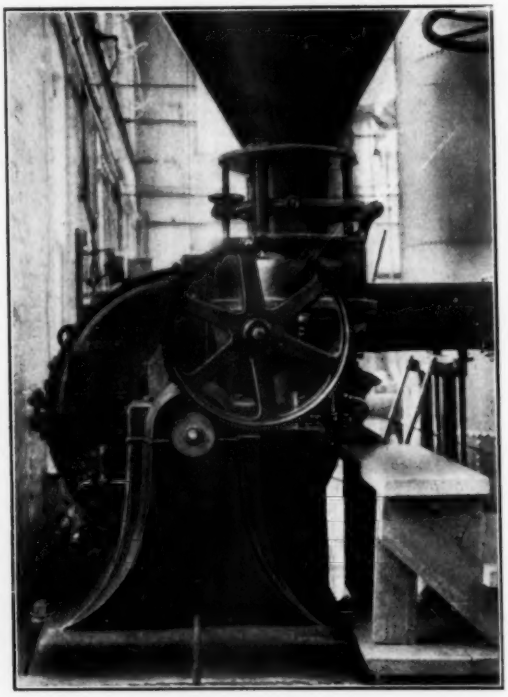

FIG. 3 FUEL PULVERIZER AND MIXING MACHINE

used to supply gas fuel to engines for the generation of power and to open hearth furnaces, being known as the Marconnet Gasogene.

12 The Hirt Apparatus (Fig. 1) consists of a pulverizer, *A*, a retort or furnace, *B*, a tower scrubber or other cleaning device, *C*. The fuel is broken to a reasonable uniform size of say $\frac{3}{4}$ in. by its passage through a crusher or griffin mill, from which it usually passes through a storage hopper to the pulverizer. Here it is ground to a satisfactory degree of fineness in the presence of air. Not only is a high degree

of intimacy on the part of the elements secured, but by this arrangement coal containing a maximum of 12 per cent to 15 per cent of moisture may be ground without pre-drying. The mixture lacking sufficient air to permit complete combustion, is then admitted tangentially into the producer or retort through opening *B* (Fig. 3). After combustion, the gas takes an upward course through the gasifying chamber and passes down the central passage, escaping at *BB* into the scrubber.

13 Heretofore the difficulty experienced in operation with pulverized fuel has been caused largely by the high heat of combustion

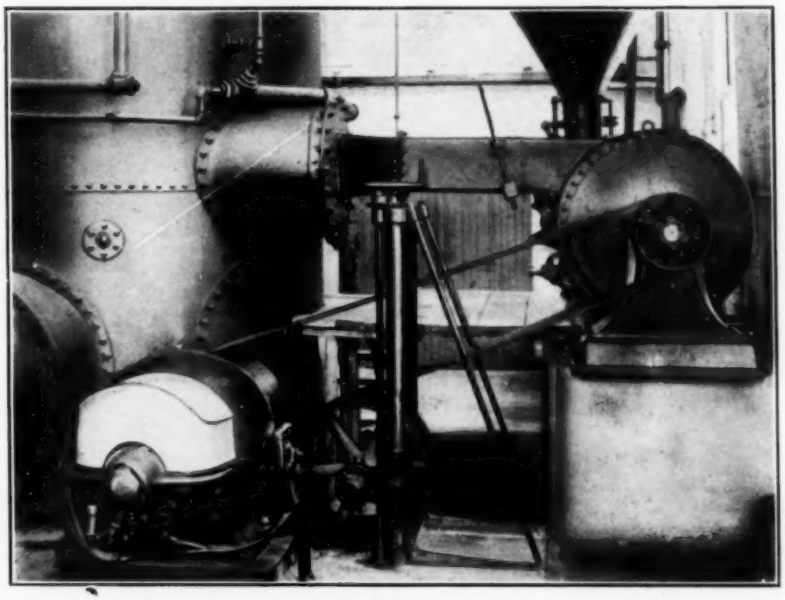

FIG. 4 PULVERIZER AND PRODUCER CONNECTIONS

and the impossibility of maintaining a refractory material under such conditions of intense temperature. It must be noted, however, that in the operation of this producer the combustion is incomplete. In starting up the producer it is necessary to permit complete combustion for a sufficient period to raise the linings to the heat of gasification, this temperature being subsequently maintained by the reaction of gasification in the natural process of manufacture within the apparatus. According to Alexander M. Gow,[1] 4450 B.t.u. are liberated

[1] Trans. Engineers' Society of Western Pennsylvania, May 1903, p. 14.

when a pound of carbon is burned or oxidized to CO. Assuming that the function of this producer is to oxidize carbon to CO, and inasmuch as the weight of the entire products of combustion of one pound of carbon burned to CO is 6.76 lb.,[2] by substituting these values in the

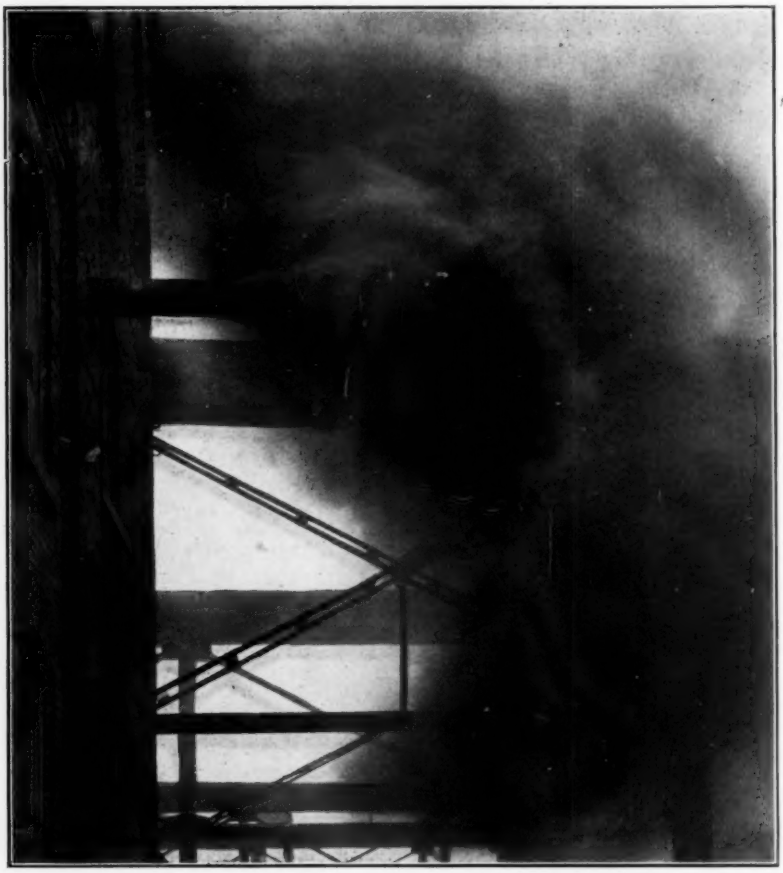

FIG. 5 3000 H.P. IN GREEN GAS DISCHARGED FROM PRODUCER THROUGH 12-IN. OUTLET

formula $t = \frac{(B.t.u.)}{W\,X\,Z}$ and taking an average specific heat for the products of combustion, the theoretical temperature derived would be practically 2240 deg. fahr. The oxidation of carbon[3] begins at the

[2] Ingalls, Metallurgy of Zinc and Cadmium, p. 264.
[3] Ingalls, Metallurgy of Zinc and Cadmium, p. 280.

low temperature of 400 deg. cent. (752 deg. fahr.), the reaction being complete at 995 deg. cent. (1823 deg. fahr.). These facts merely serve to indicate that the exothermic reaction $2\,C + O_2 = 2\,CO$ would be sufficient to supply all heat necessary for the operation of the producer.

TABLE 1 ANALYSES OF PRODUCER GAS

Carbon Monoxide, %	23.7	27.5	26.5	27.0	24.5	15.85	13.52	12.20	18.2	13.8	18.9
Carbon Dioxide, %	3.9	2.8	2.9	5.0	3.9	9.20	8.10	7.60	4.9	8.0	9.4
Hydrogen, %	10.0	11.5	11.0	9.5	9.8	6.17	11.51	10.50	12.2	10.4	12.2
Methane, %					3.4	4.09	5.17	3.20	2.1	2.5	
Oxygen, %						1.40	0.30	0	0.1	0	
Nitrogen, %						63.29	61.40	66.50	62.4	64.8	
Illuminants, %									0.1	0.5	
B.t.u. per Cu. Ft., Total									128.89	119.70	

* Steam admitted to upper chamber.

TABLE 2 PROXIMATE ANALYSES OF COAL

Moisture, %	0.52	1.20*	0.73
Vocatile Matter, %	17.50	32.95	17.52
Fixed Carbon, %	72.48	59.64	76.80
Ash, %	9.50	6.21	4.95
Sulphur, %	1.24		
B.t.u. (dried)		13.925	14.550

*Analysis of ash from above coal: silica, 43.62; aluminum and iron oxide, 42.00; lime, 5.74; magnesia, 2.22.

14 Perhaps the only serious difficulty met with in the continuous and uniform operation of the apparatus was caused by the construction of the producer upon the hypothesis of the inventor that all coals could be carried up at a temperature at which the ash would fuse, so that it could be removed in the form of slag. This was an error which soon developed. It has been demonstrated that only fuels containing easily fusible ash can be handled in such a manner, and that these fuels are the exception, rather than the rule. The apparatus having been constructed upon this premise, the removal of ash was a clumsy and inconvenient performance. It was necessary to accumulate an ash bed sufficiently deep to seal the producer and then gradually and carefully withdraw it from the bottom. This difficulty, however, would be easily remedied in a producer designed with the knowledge of the foregoing experiments. Either a water-sealed bottom or a conical dumping bottom would be entirely convenient and economical of operation.

15 In the experiments herein cited the pulverizer was driven by an electric motor. In commercial operation, however, the sensible heat of the effluent gases would be more than sufficient to generate steam to drive all auxiliary apparatus and even to supply a surplus for any useful purpose. The interposition of a waste-heat boiler between the producer and the scrubber, such as is used in the Loomis-Pettibone apparatus or in connection with water-gas sets would unquestionably act with entire satisfaction.

16 Bituminous coals of a wide range were used and the operation of the producer upon fuels containing up to 30 per cent of ash and 15 per cent of moisture was commercially demonstrated. Some typical analyses of the gases, as made by the Pittsburgh Testing Laboratories are given in Table 1.

17 There is, however, a definite ratio existing between the fuel used, the degree of fineness to which it is ground and the time the gas remains within the producer. That is, adjustment should be made to suit the chemical analysis and the physical nature of the given fuel. The length of the downcomer should depend upon both of these elements, the length varying, in all probability, inversely as the percentage of volatile matter contained in the coal.

18 The success of these experiments and the field of development opened up thereby will undoubtedly have a powerful impetus to the development of large gas-generating units, for the results obtained, as reflected in the analyses of the gas, show a very high efficiency for the apparatus and a remarkable uniformity in its product. Considered as a whole, it presents at least one available source of gas supply for the heavy-duty gas engine.

TEST OF A 10,000-KW. STEAM TURBINE

WITH A BRIEF DESCRIPTION OF FEATURES OF CONSTRUCTION

By Sam. L. Naphtaly, San Francisco, Cal.

Member of the Society

The steam turbine has experienced, as is quite universally known, the most rapid development of any form of prime mover, and its application has been extensively broadened within the last few years. Recent proceedings of this Society contain, in the paper on small steam turbines by Geo. A. Orrok and on tests of a 15,000-kw. engine-turbine unit by Messrs. Stott and Pigott, useful data on small units and low-pressure turbine operation, respectively.

2 It is the intent of this contribution to record the attainment in the design and operation of a complete-expansion turbine of 10,000-kw. normal rating, installed in the latter part of 1909 in the main power station of the City Electric Company, San Francisco, Cal., under the author's management, and recently tested under the direction of J. G. White and Company, consulting engineers.

3 The object of the test was to determine the general steam consumption of the turbine unit under everyday operating conditions and further to determine whether the builder's guarantees of economy, generator, temperature, etc., had been complied with.

4 The contract with the builder specified a turbine of 10,000-kw. normal capacity with an additional overload capacity of 50 per cent operating with steam at 175 lb. gage pressure, superheated 100 deg. fahr. and with 28-in. vacuum, measured in the exhaust pipe and referred to a 30-in. barometer. Under the above conditions, operating at 1800 r.p.m., the guaranteed performance was as follows:

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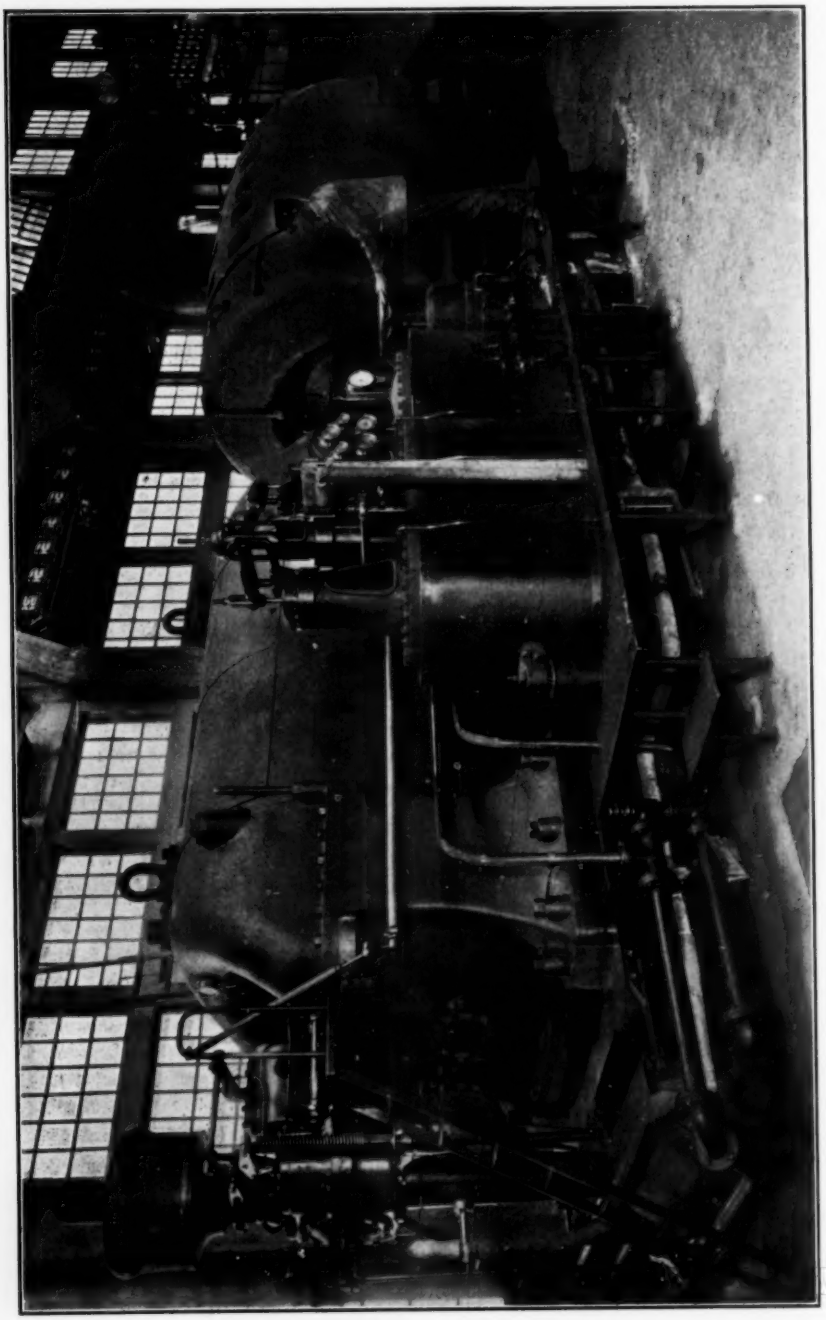

FIG. 1 GENERAL VIEW OF TURBO-GENERATOR

Full load	10,000 kw.	14.3 lb. per kw-hr.
½ load	5,000 kw.	16.2 lb. per kw-hr.
1½ load	15,000 kw.	15.3 lb. per kw-hr.

5 The generator was designed for a 60-cycle, 3-phase current, its normal rating being 525 amperes per terminal at 11,000 volts, the voltage maintained constant at all loads by means of a Tirrill regulator. The generator is of the enclosed type and is provided with a direct-connected exciter, driven from the end of the main generator shaft.

6 The generator was specified to have a temperature rise in any part above the temperature of the ingoing cooling air, not exceeding the following:

Full-load current, normal voltage, for 24 hr., 40 deg. cent.
1¼-load current, normal voltage, for 24 hr., 50 deg. cent.
1½-load current, normal voltage, for 24 hr., 60 deg. cent.

7 The steam turbine is of the double-flow type, containing both impulse and reaction elements. The exterior of the unit, as installed in the power plant is shown in Fig. 1, while Fig. 2 shows a longitudinal section of the turbine.

8 Certain features of construction of the turbine are as follows:

a Double-flow design, employing a single high-pressure impulse wheel centrally located. A division of steam between two similar and opposed intermediate and low-pressure reaction elements, one-half flowing through the annulus surrounding the high-pressure wheel, shown by arrows in Fig. 2. The large capacity and high rotative speed of the unit make it possible to utilize the double-flow construction, which has many obviously desirable features. Indeed it may be said that for this capacity and rotative speed, the double-flow construction is imperative, since in a single-flow machine of the same capacity and speed the blade lengths in the low-pressure section will be so great as to preclude the possibility of sound mechanical construction or efficient steam distribution.

b Symmetry of cylinder structure resulting from the double-flow design, favors the production of the casting with least initial strain, and permits of uniform distribution of temperature strains.

c High speed reduces the metal masses, ensuring greater homogeneity of casting with a resulting increased factor

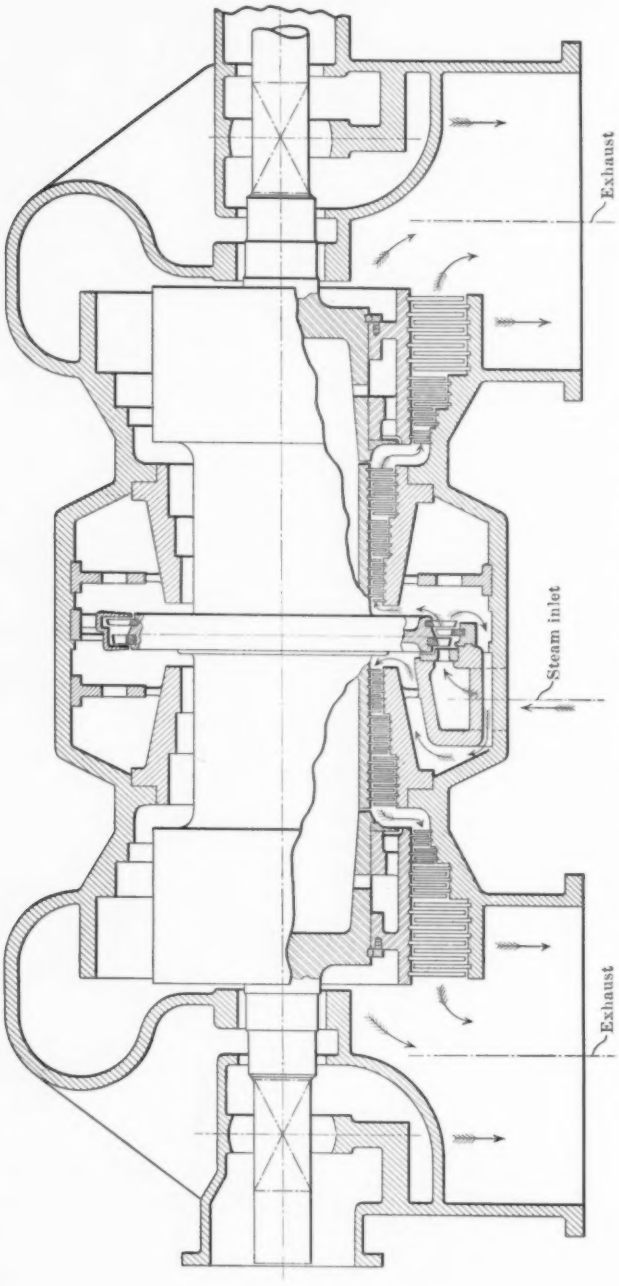

FIG. 2 SECTIONAL VIEW OF TURBINE

of safety, since the same peripheral speeds and centrifugal stresses virtually obtain as in the lower rotative speed designs.

d Turbine cylinder simplified with intermediate stationary element cast separately and hence subject to less internal strains. Provision is made for the ready removal of these parts.

e There are no feet cast on the cylinder for supporting it on the bedplate. Instead, there are provided cast-iron chairs, two at each end, as seen in Fig. 1. The cylinder is carried by these chairs in a horizontal plane close to the axis of the turbine, the advantage being that with this construction the alignment of the coupling is less affected by temperature changes. The cylinder is free to slide on these chairs permitting unrestrained expansion of the parts. In fact the turbine is not secured at any point except where it joins the generator inboard bearing pedestal which, however, is rigidly bolted to the plate.

f The governing apparatus, while containing many improvements in detail, presents no particularly novel features. There are two governor-controlled inlet valves, each admitting steam to a group of nozzles; full load being carried on the primary valve alone. Overloads are maintained by a group of nozzles operated by the secondary valve.

9 These main valves and their operating mechanism are shown in detail in Fig. 3. They are hydraulically operated, oil under pressure being supplied by the oil pump driven by the turbine. The entire output of this pump is not necessarily used by the governor, the surplus escaping through a spring-loaded valve, which together with that discharged from the valve-operating mechanism, furnishes the oil supply for the bearings. The operation of the hydraulic gear is, as is seen from Fig. 3, accomplished by the familiar relay and floating lever. Hitherto, it has been customary to construct the relay for a mechanism of this character without lap. If it does have lap, either negative or positive, the amount of this lap must be traveled before the mechanism can respond to the governor. A departure is here made from previous practice in providing the relay plunger with both inside and outside laps. The relay is kept oscillating a small amount by means of a cam connected to the governor linkage, sufficiently to uncover slightly the ports at each oscillation, causing a correspond-

ingly slight motion of the main operating piston. The effect of the governor itself on this relay, is, of course, to change its plane of motion, and hence response to the least change in position of the governor weights is thus assured.

10 The condenser is of the Wheeler-surface dry-tube type, equipped with primary feed heaters, turbine-driven centrifugal hotwell pump, and rotative dry vacuum pump. The condenser is located immediately below the turbine and is provided with two openings connecting with the exhaust at each end of the turbine. It contains 25,000 sq. ft. of 1-in. tube, No. 18 gage. A 42-in. cast-iron conduit, located so as to be submerged even at extreme low tide, conducts salt water direct from the bay of San Francisco to the plant. After being pumped through the condensers the salt water is returned to the bay through a suitable channel.

11 The turbine generator is of the builder's most recent four-pole construction. The field is of nickel steel and is made up of two halves joined end to end by shrink links. Each half is integral with its shaft, which renders any hole for the shaft unnecessary and consequently considerably increases the strength of the revolving field. The field winding is done under heavy tension, which results in a very solid mechanical construction. The rotor is provided with a series of turbine fan blades, and the ends of the armature winding are covered by stationary end bells which, in addition to protecting the winding serve as means of conducting the cooling air from the air ducts to the machine. This air is drawn from the conduits by means of the turbine blowers through the armature winding and is forced into the air gap, whence it passes outward through the armature laminations and is discharged into an exhaust air duct.

12 As this was the first generator of this design constructed, the City Electric Company insisted that tests be carried out by the builders before shipment, which showed an electrical efficiency at ¼ load of 92.2 per cent; at full load of 97.6 per cent and at 1½ load of 98.2 per cent.

13 From the compromise tests which it was possible to make in the works, it was figured that the temperature rises at full load, 100 per cent power factor, would be 28 deg. on the armature laminations and 18 deg. on the field, by thermometer, the temperature rises by resistance being 22 deg. on the armature winding and 35 deg. on the field winding.

14 The tests by J. G. White and Company confirm these figures, their results showing that on a load of 5300 kw. at 89 per cent power

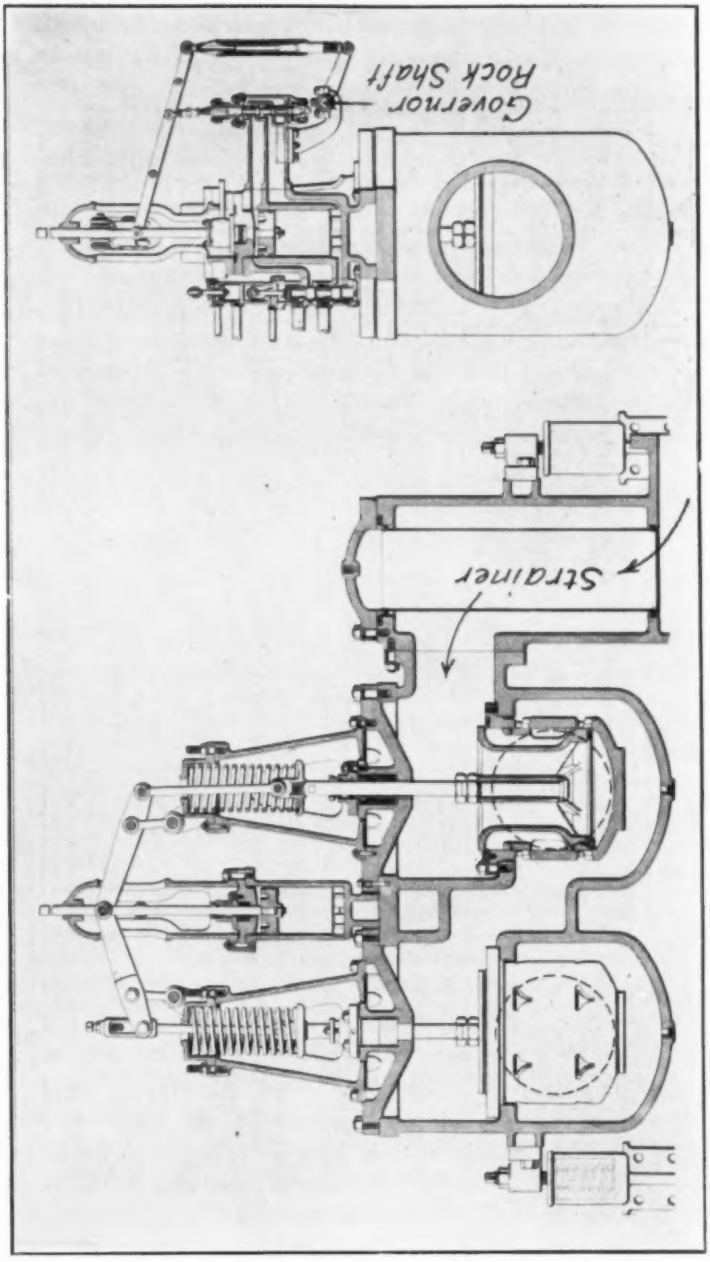

FIG. 3 GOVERNOR OPERATING MECHANISM

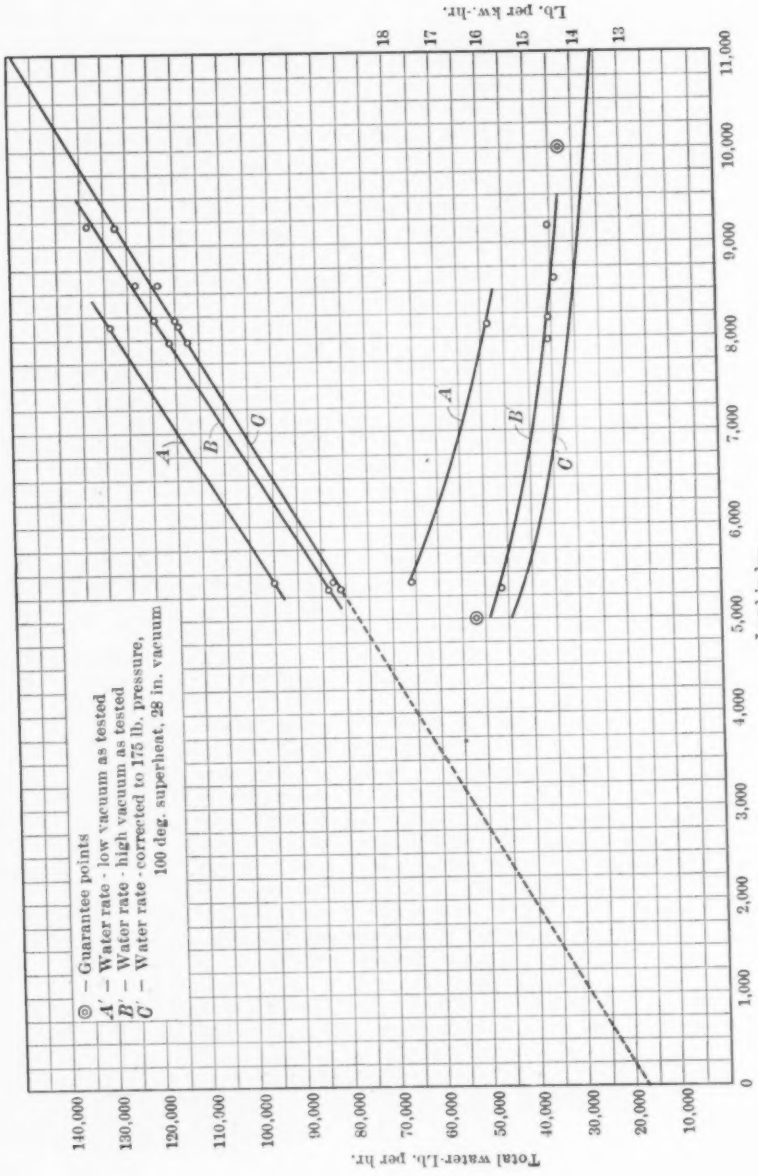

FIG. 4 ACTUAL WATER-RATE CURVES OBTAINED FROM TESTS

factor, that is, 6000 k.v.a., the maximum temperature rise of the armature was constant at 27 deg. On a load of 9300 kw., 89 per cent power factor, that is, 10,400 k.v.a., the maximum temperature rise was constant at 31 deg. These figures are well within the guarantees.

DETAILS OF TURBINE TEST

15 In what follows details are given of the turbine test made after installation, the results being shown by the curves, Fig. 4 and Table 1. It is unfortunate that the unit had to be maintained carrying the station load during the tests. During the high-load tests, it was the only unit operating in the station, so that observations had to be made under these conditions, with the load variations incidental to station operation. In all, seven runs were made, two of which, *E* and *G*, were at low vacuum for the purpose of establishing the effect of variations of vacuum on this machine. In Table 1, both the Rankine

TABLE 1 SUMMARY OF TEST OF 10,000-KW. TURBINE

CITY ELECTRIC CO., SAN FRANCISCO, MARCH 1910

Run	Date 1910	Duration, hours	Actual Load, kw.	P. F., per cent	Steam Pressure, lb. Gage	Superheat, Deg. Fahr.	Vacuum 30-in. Bar.	Water per hour, Total, Lb.	Water per kw-hr. as Tested	B.t.u. per kw-hr.	Rankine Cycle Eff. as Tested	Thermal Eff., Per Cent	Lb. per kw-hr. Corrected 175 lb. 100 Deg. Sup. 28-in. Vac.	Remarks
A	3–14	1.5	7972	90	171	58	28.28	116238	14.581	15378	66.9	22.20	14.11	High Vacuum
B	3–14	2.0	8563	88	168	59	28.18	123542	14.427	15062	68.0	22.65	13.88	High Vacuum
C	3–14	2.0	8198	91	169	60	28.10	119655	14.596	15414	67.6	22.10	14.04	High Vacuum
D	3–14	2.0	9173	91	167	59	27.90	133672	14.572	15360	69.0	22.23	13.88	High Vacuum
E	3–15	3.0	5333	88	173	54	28.34	83478	15.655	16493	61.8	20.70	15.21	High Vacuum
F	3–15	4.0	8148	88	167	60	26.16	129151	15.855	16782	69.5	20.35	14.07	Low Vacuum
G	3–16	3.0	5401	88	174	56	26.16	95120	17.611	18587	62.2	18.35	15.24	Low Vacuum

Note: The above summary of the entire test varies but ½ of one per cent from the average of the 15 minute readings taken during the test.

cycle and thermal efficiencies have been given in addition to the rate of steam consumption in pounds per kilowatt-hour, which is the usual method of stating the performance of the steam motor. The thermal efficiency considers only the heat in the steam from the boiler, and is of use only for comparing results with other forms of prime movers, such as internal combustion engines. The Rankine cycle efficiency, or efficiency ratio as it is sometimes called, is the more equitable measure for comparison of steam motors, as it reckons with the work done

between the limits of steam leaving the boiler and exhaust entering the condenser. Taking the heaviest load carried, run *D*, the efficiency ratio obtained was 69 per cent including generator and field losses which, I believe, is some improvement over results hitherto obtained for a complete-expansion turbine.

16 The performance of a steam turbine follows the Willans right-line law over a great range of its capacity, which gives a valuable check on the accuracy of the test points and reduces the number of necessary runs to a minimum. Furthermore, the performance of a turbine may be accurately predicted at loads beyond the range at which tests

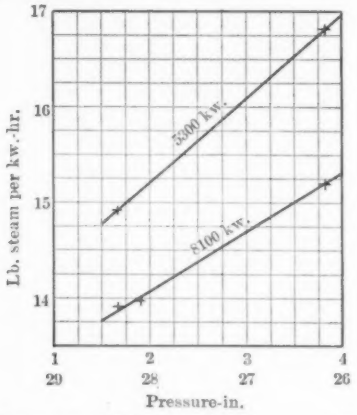

FIG. 5*a* TESTS FOR OBTAINING VACCUUM CORRECTION

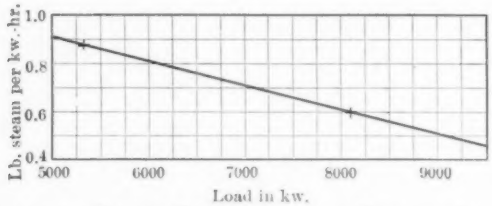

FIG. 5*b* CHANGE IN STEAM CONSUMPTION AT VARIOUS LOADS PER 1 IN. CHANGE IN VACCUUM

have been run. Referring to Fig. 4, it is reasonable to expect that if a higher load had been available, the steam consumption would have further improved until the opening of the secondary valve. Allowing for a 10-lb. drop through the inlet valves, the load would have been approximately 11,000 kw., when, as seen by Fig. 4, a steam consumption of less than 13.7 lb. per kw-hr. would have been obtained, with an efficiency ratio of 71 per cent.

17 It is acknowledged that slightly superior efficiency exists with the combined engine and turbine unit, reported by Mr. Stott, at 72 per cent, the engine unit particularly making a remarkable showing. On the heat consumption basis, however, the San Francisco unit is approximately only 8½ per cent in excess of the combined reciprocating and turbine unit, but it is obvious that this advantage in steam consumption is offset by the advantage of the simple turbine unit without the complication of the reciprocating engine, which involves greater first cost, greater floor space and cost of maintenance and necessitates shutting down the unit while the reciprocator is being adjusted, or else further complicating the system by use of an auxiliary governor and high-pressure valves on the low-pressure turbine.

DETAILS OF STEAM CONSUMPTION TEST

18 As mentioned before, it was necessary to test the unit while in commercial service; consequently the loads of the turbine during the various tests were subject to variations which probably may have lowered the economy.

CORRECTIONS

19 As the operating conditions specified by contract, namely 175 lb. gage pressure, 100 deg. superheat, and 28 in. vacuum, could not be maintained throughout the test, correction factors had to be determined upon, and an agreement was reached previous to the tests as follows:

Superheat, 1 per cent change in steam consumption for 10 deg. in superheat, which is the correction factor commonly employed for turbines.

Steam Pressure, ½ per cent for 10-lb. change in pressure. (As there was no reason for the full pressure not being maintained, these were however insignificant.)

Vacuum, as the vacuum correction is affected by the design of the turbine, the amount of the correction could not be determined in advance of the tests, therefore runs *E* and *G* were made. From these and from the other tests it was found that 1 in. of vacuum affected the steam consumption 3 per cent and 6 per cent at full load and half load respectively. These vacuum corrections are shown in Fig. 5*a* and Fig. 5*b*.

20 All important readings were taken at 5-minute intervals except in cases of energy output and water measurement for which 15-minute integration proved adequate. Figs. 6 to 10 inclusive, present graphically the principal logs of the tests, which show only small fluctuations of the pressure and temperature conditions, and consistent changes in load and steam consumption, insuring reliability of the average values.

21 The electric output of the unit was obtained with a General Electric polyphase wattmeter, checked by three single-phase integrating wattmeters, tested under the supervision of Frank E. Smith, consulting engineer, and Pacific Coast representative of the Weston Electrical Instrument Company. Its complimentary current and potential transformers were similarly checked with standards.

22 Steam consumption measurements were made by actually weighing the water discharged from the surface condenser which was delivered by a 5-in. single-stage centrifugal pump through 6-in. piping to a set of four weighing tanks. These tanks were $3\frac{1}{2}$ ft. in diameter and 5 ft. deep. Each tank was on a 2000-lb. platform scale. The supply pipes and tanks were furnished with 5-in. quick-opening valves. Scales were tested and certified correct by the Howe Scale Company of San Francisco.

23 Tests were made for leakage of the cooling water into the condenser. As sea water is used for cooling, these tests were made by adding silver nitrate to samples of the condensed steam. No indications of leakage were found and hence no allowance was made for leakage.

24 The shaft glands were sealed by water taken from the condenser discharge before weighing and the leakage from outside of the glands was caught and measured. In this way no special allowance was necessary for gland sealing water. The stuffing boxes of the centrifugal hotwell pumps were sealed with water from the discharge. A small leakage occurred here which was caught and added to the leakage from the main unit gland.

25 All pipes connected with the condenser or piping system, by which water might escape from the discharge or leak into the discharge water, were disconnected, blanked or arranged with two valves with an opening between for detecting leakage.

26 Observations were made of the pressure and temperature of the steam at the throttle, pressures within the turbine at inlet, intermediate and low pressure points. The vacuum was indicated by a mercury column and the atmospheric pressure by a mercury barometer.

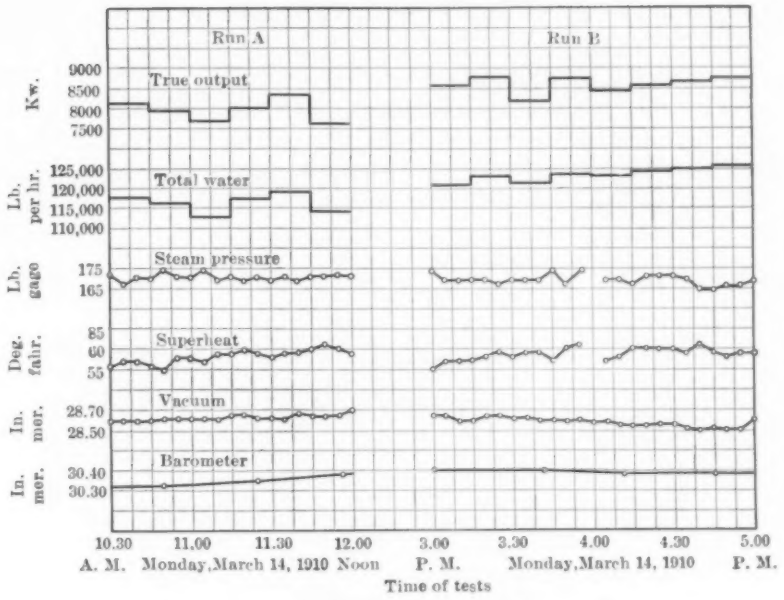

FIG. 6 LOG OF TEST DATA—RUNS A AND B

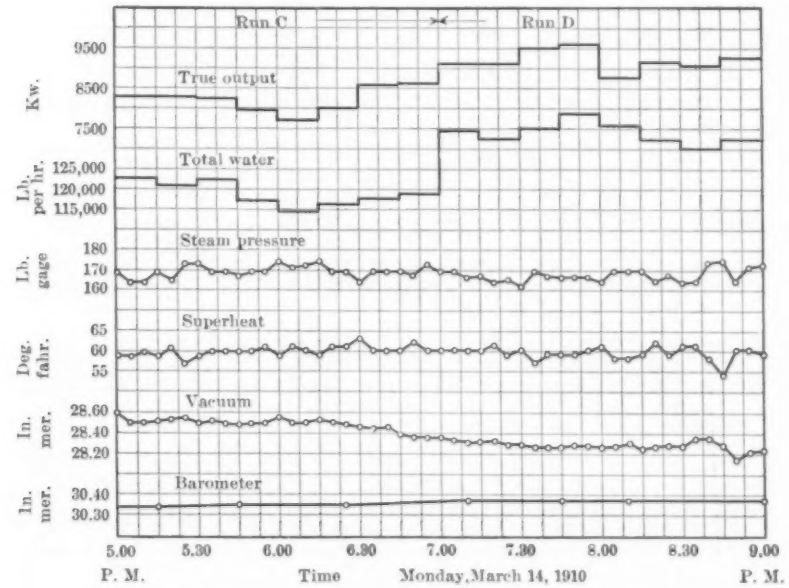

FIG. 7 LOG OF TEST DATA—RUNS C AND D

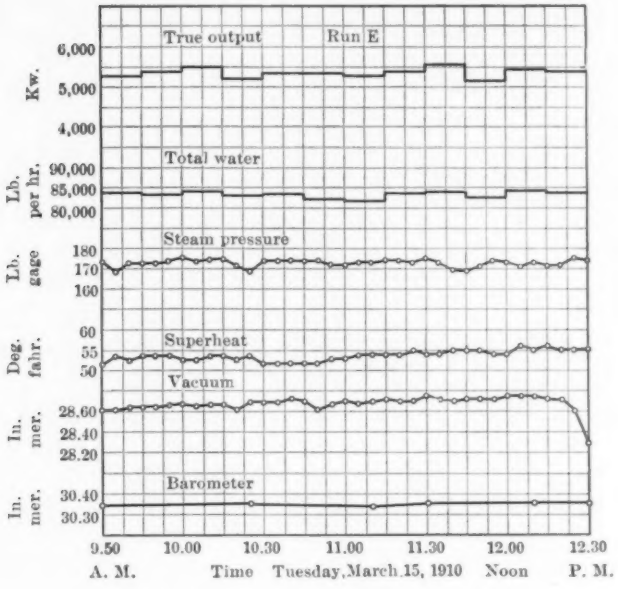

FIG. 8 LOG OF TEST DATA—RUN E

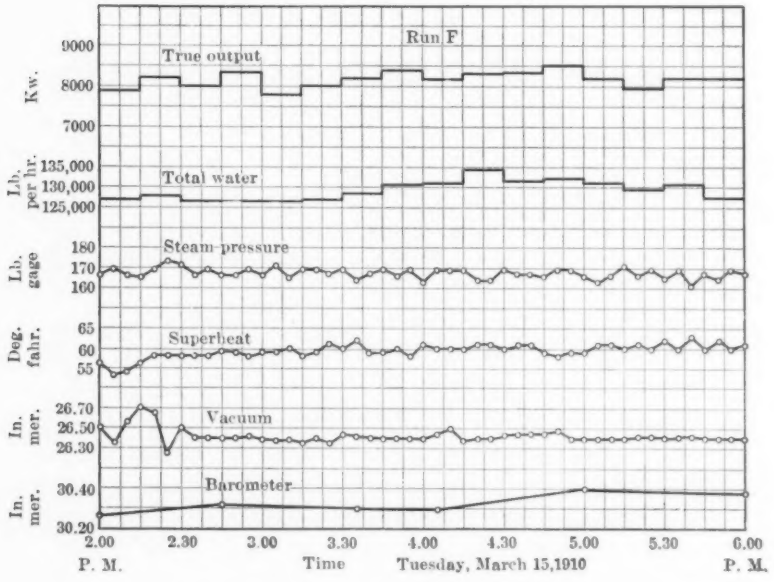

FIG. 9 LOG OF TEST DATA—RUN F

The steam gages were tested on a Crosby dead-weight testing machine. The steam gage at the throttle was 1 lb. high at the working range of pressure. The steam temperatures were taken with a 15-in., 600-deg. fahr., nitrogen-filled thermometer, made by Henry Green of Brooklyn, N. Y. This thermometer was one of four new ones. As there was practical agreement of the four, by check before the tests, the temperature readings were considered practically correct. The thermometer was placed in a thermometer well in the steam pipe close to the throttle valve. The thermometer well was partly filled

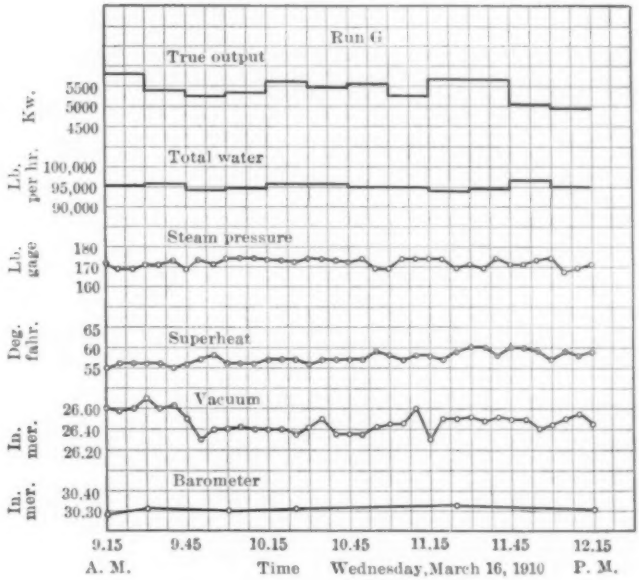

FIG. 10 LOG OF TEST DATA—RUN G

with mercury and the remainder of space with oil. The thermometer entered the well to the 400-deg. mark. As the steam temperature was about 430 deg., the effect of stem exposure was small. One degree has been added to the temperature for this correction.

27 The vacuum gage was a Hohman and Maurer instrument. Connections were made with a $\frac{3}{4}$-in. pipe to both exhaust nozzles of the turbine. The piping was provided with a valve admitting air to blow back to the condenser any condensation in the pipe. As the mercury column has a tube of small bore, 0.1 in. or less, allowance

was made for capillary depression of the mercury by adding 0.1 in. to the average of the readings.

28 The barometer was compared with the barometer of the office of the U. S. Weather Bureau and found to be 0.1 in. low.

The following is a summary of corrections applied to readings obtained during the steam tests:

Pressure of steam supply	Subtract 1 lb.
Temperature of steam supply	Add 0.1 deg. fahr.
Vacuum column reading	Add 0.1 in.
Barometer	Add 0.1 in.

29 It would encumber the paper to publish the complete detailed logs of these tests. The author will, however, be pleased to place them at the disposal of any interested members.

TEST OF A 9000-KW. TURBO-GENERATOR SET

By F. H. Varney, San Francisco, Cal.

Member of the Society

For about five years prior to 1908 the City of Oakland had been practically dependent for its electrical energy on the water-power stations and transmission lines of the Pacific Gas and Electric Company, located 125 to 150 miles from Oakland. In the year 1908 it became evident that this service would necessarily have to be bettered, not alone for capacity, but also for regulation, and after considerable preliminary estimating, it was decided on the first day of July of that year to endeavor to have a turbo-generator set installed and operating in time for the Christmas holidays. Plans and specifications were immediately prepared and to hurry the work as much as possible a heavy bonus and penalty clause was made a part of every contract.

2 The delivery of the turbine seemed to be the one point that might cause delay, as boilers, superheaters, steam piping, condenser and all auxiliaries were promised on time. The turbine was, however, shipped 38 days in advance of promised shipment and the work progressed without delay until the unit was started and put into regular service on December 18, 1908, thus making 171 days from the beginning of the plans and specifications to the successful operation of the station. It is interesting also to know that the station, including turbo-generator, boilers, steam piping and auxiliaries, buildings, crane and everything necessary for a complete steam plant, excepting land, cost $51 per kw.

3 It was with considerable satisfaction that the turbine was started, as this was one of the driest years the water-power station had ever experienced and the demand for power greatly exceeded that of previous years.

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4 The turbine was immediately put in parallel with the hydro-electric system, which consists of eleven water-power stations, three reciprocating-engine stations, and one gas-engine plant. It operated perfectly in every particular and soon demonstrated the superiority of this class of prime mover over reciprocating steam or gas engines, both in regulation and in maintenance.

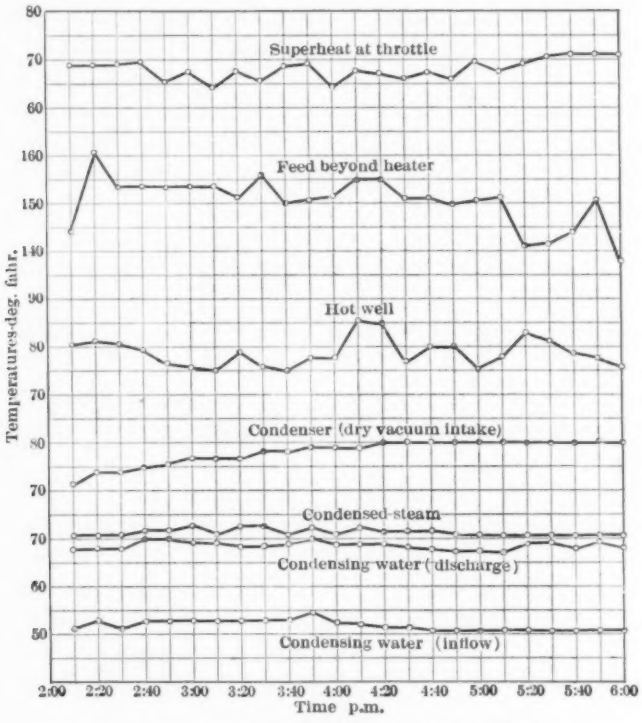

FIG. 1 LOG OF TEST DATA—FIRST TEST

5 The plant is situated on the Oakland estuary, between Grove and Jefferson Streets on First Street, distant about one mile from the center of Oakland. The estuary is a branch of the San Francisco Bay and has an ample supply of clean salt water from which circulating water for the condenser is drawn. A wharf was built into the estuary for the purpose of landing the fuel supply and the Southern Pacific Railroad tracks adjoin the First Street side of the station. The location is considered ideal.

6 The apparatus installed consists of a 9000-kw. vertical Curtis turbo-generator (maximum rated), Worthington condenser and vacuum pumps, and eight 754-h.p. McNaull water-tube boilers. The plant is oil-burning, using what is known as the back-shot burners. The boilers are equipped with superheaters for 100 deg. superheat.

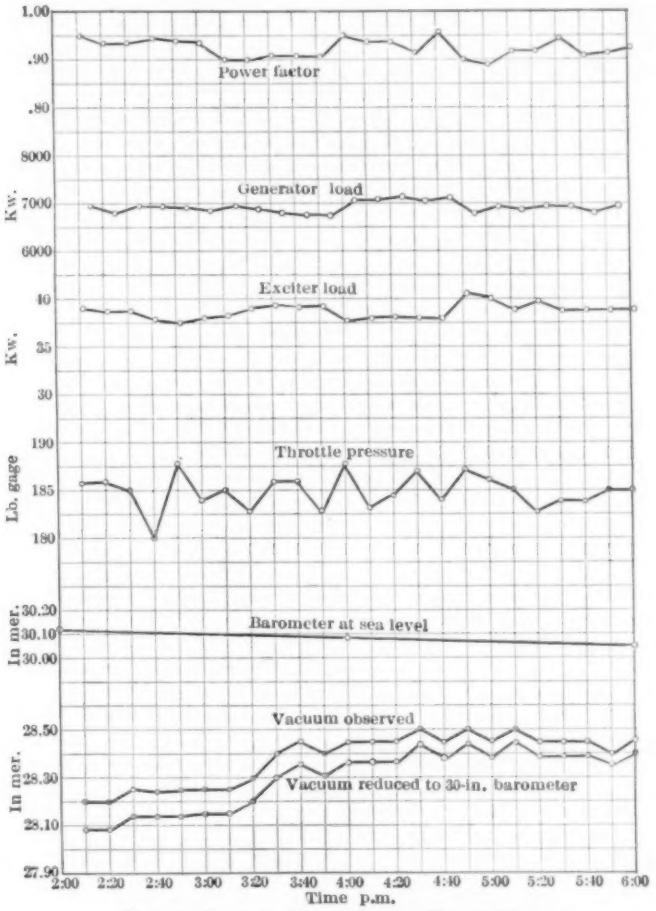

FIG. 2 LOG OF TEST DATA—FIRST TEST

7 Owing to the urgent need for the plant, the efficiency test was postponed until the station had been in operation for 14 months. The conditions of the test were as follows: The turbo-generator was run on a closely regulated commercial load, which was maintained as

nearly uniform as possible by the load dispatcher. Two runs of four hours each were made at loads approximating 7000 kw. and 9000 kw. The boilers were operated on the usual program, the number employed being adapted to the load carried. No attempt was made to obtain complete data regarding the economical operation of the boilers.

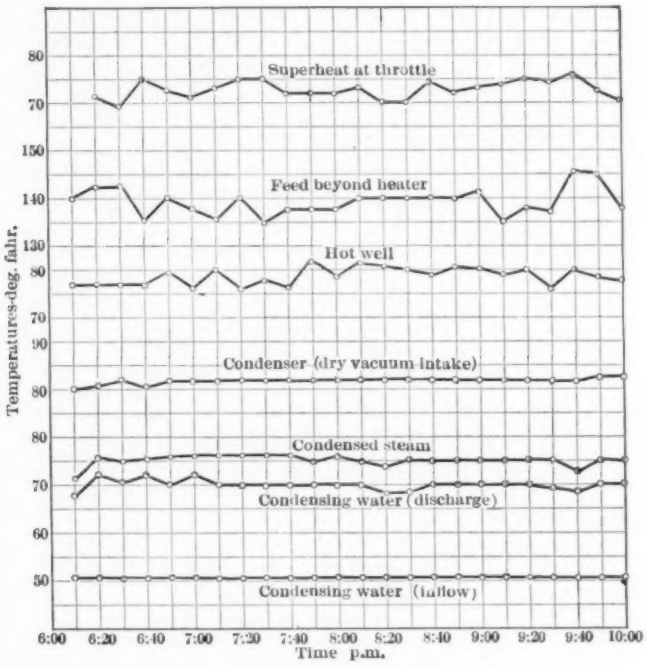

FIG. 3 LOG OF TEST DATA—SECOND TEST

8 In view of these conditions, it was decided to provide for the measurement of the following items:

a Water from turbine
b Total make-up and auxiliary water
c Power delivered by generator at switchboard
d Exciter output
e Pressures and temperatures required to complete and interpret the above observations.

9 Measurements of water were made by tank weighings with standard scales in lots averaging 1800 lb. to 1900 lb. and in accordance

with the general methods recommended by the engineering societies for such purposes. The power delivered by the generator was measured by duplicate installations of integrating wattmeters connected in accordance with the three-meter method for three-phase circuits. Observations of all electrical readings and of all pressures and temper-

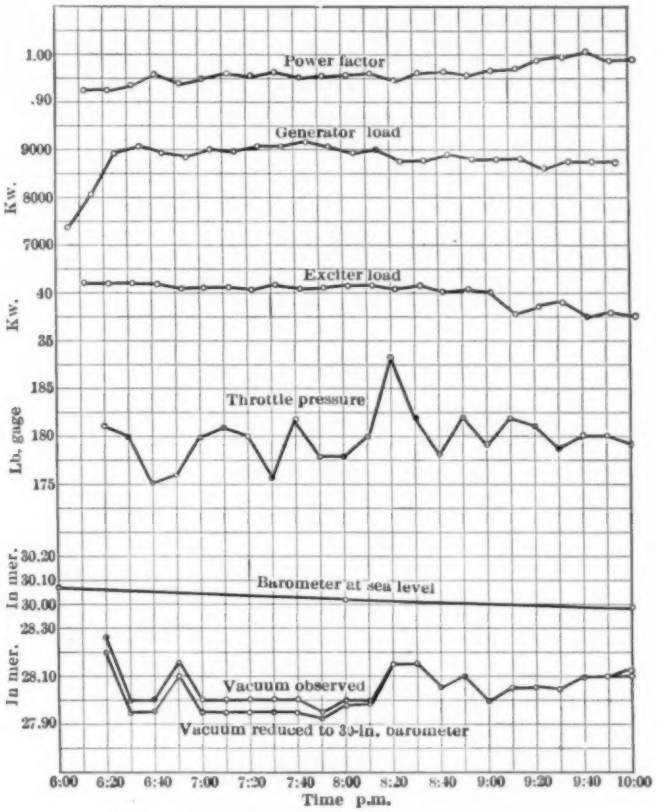

FIG. 4 LOG OF TEST DATA—SECOND TEST

atures were made at ten-minute intervals. Weighings of water were made at intervals as determined by the load. The level of water in the feed tank and the condition of the weighing tanks at the end of each half-hour period were also noted, thus providing for a closure of the test at any such period. Leakage tests of the condenser and of the wet vacuum pump seal were made before and

after the test and a mean of the two values was used as the leakage correction.

10 All apparatus and instruments employed were carefully calibrated by reference to absolute standards or to others as near to them as possible. The scales employed were tested both before and after the run by the use of 50-lb. weights loaned for the purpose by the Fairbanks Company. All pressure gages were tested by the use of a dead-weight testing apparatus. The indications of the mercury vacuum gage were accepted as accurate without further test. The integrating wattmeters were calibrated before and after the run. All thermometers were compared with standards certified by the United States Bureau of Standards.

11 The general and economic results for each run as a whole are given below. Figs. 1 to 4 show the data worked up for ten-minute intervals and plotted on a time axis. The actual turbine results were reduced to the conditions specified in the contract, by means of the following schedule of corrections:

CONTRACT SPECIFICATIONS

1 Steam pressure at throttle	175 lb. gage
2 Superheat	125 deg. fahr.
3 Vacuum	28 in.

4 Steam consumption

Generator output (kw.)	Lb. per kw-hr.
5000	16.75
7000	16.40
9000	16.40

CORRECTIONS

1 For each 10 lb. pressure	1 per cent
2 For each 12½ lb. deg. superheat	1 per cent
3 For each inch vacuum	1.08 lb. per kw-hr.

GENERAL AND ECONOMIC RESULTS

1 Time, February 18, 1910	2.10 p.m. to 6.00 p.m.	6.00 p.m. to 10.00 p.m.
2 Total water with all corrections, lb	520,837	650,600
3 Average load, kw	6,922	8,775
4 Water from turbine as weighed (corrected for scales), lb	428,704	562,579

5 Water leakage correction, lb	−2,461	−2,568
6 Corrected water from turbine, lb	426,243	560,011
7 Water per kw-hr., lb	16.06	15.95
8 Temperature of condenser, deg. fahr	78.1	81.9
9 Temperature of condensing water, inflow, deg. fahr	52.15	51.0
10 Temperature of condensing water, discharge, deg. fahr	66.50	70.0
11 Rise in temperature of condensing water, deg. fahr	14.35	19.0
12 Vacuum in condenser, reduced to 30 in. barometer, in. mer	28.30	28.03
13 Exciter output, kw	38.9	40.0

FINAL CORRECTED VALUES

6.00 p.m. to 10.00 pm.

Correction for superheat, per cent	− 4.13
Correction for pressure, per cent	+ 0.48
Correction for superheat and pressure, per cent	− 3.65
Correction for vacuum, lb	+ 0.03
Water rate corrected for vacuum, lb	15.98
Water rate with all corrections, lb	15.42

THE FIELD FOR GRINDING

C. H. Norton, Worcester, Mass.

Non-Member[1]

Grinding in various forms has been known to man from the very beginning of history, yet it is doubtful if many engineers have a clear conception of the field for metal grinding. Experience (as a specialist) covering twenty-five years has taught me that the usual thought of grinding is that it is a slow, tedious, expensive, but sure method of obtaining accuracy, and that where great accuracy is not required grinding should not be done.

2 Webster defines abrasion as "the act of wearing or rubbing off; the wearing away by friction, as the abrasion of coins." Abrade, "to waste or wear away by friction, as to abrade rocks." He defines the word abraise as "rubbed smooth, as an abraised table," meaning a polished table. No doubt here is the connection between polishing and abrasion.

3 Some time within the last 75 to 100 years men discovered that a revolving polishing wheel enabled them to abrade work in such a comparatively short time that so far as polishing was concerned it was no longer slow nor tedious. But as the original word for abrasive action was "grind," and grinding was slow, men still clung to the tradition in spite of the later discovery that polishing could be done quickly. When, within the recollection of the writer, mechanics made their own solid glue and emery wheels with which to grind small hardened tool work, it did not occur to them that they could do by grinding a certain part of the work that they were using steel tools for, because it was grinding, and was slow. Moreover, all nice work must of necessity take lots of time, because our older mechanics

[1] Norton Grinding Co.

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had said so. It did not occur to them that we could ever have better grinding wheels and better machines in which to use them.

4 It was at this point in our reasoning that the majority of engineers rested and it is here that we find a large number now. All engineers admit the exactness of grinding, but most of them still believe it to be slow.

5 Appleton's Cyclopædia of Applied Mechanics, published as late as 1893, says that emery wheels are employed mainly for producing cutting edges and for smoothing surfaces. Again it says that in all cases of the employment of emery wheels in place of steel cutting tools, the operation is considerably slower, and it may be laid down as a rule that save upon metal too hard to be operated upon with steel tools, the emery wheel cannot compete with the ordinary lathe, planer, milling tool, etc. My observations convince me that a great many American engineers hold the same views.

6 As a specialist for many years, I have seen a gradual but sure increase of knowledge of grinding and have noted the widening of the field as the result, but I am not aware that the intelligent study of grinding has been taken up by professional engineers or by any institute of technology. The intelligent use of grinding yields such large returns that it warrants careful study by the very best engineering and scientific minds and a place in the courses of our technical schools. The field is constantly broadening with each year's improvements in grinding wheels and grinding machines, and it is time that men of brains and education took a hand with us to help the world to a better knowledge of the science of grinding and grinding wheels.

7 The results thus far attained warrant a change of the world's idea of grinding and instead of using it as a synonym for slowness, tediousness and drudgery, it should be a synonym for rapidity, accuracy and economy.

8 The fact about grinding with the modern grinding machine and grinding wheel (not emery wheel) is that it enables us to size all round work cheaper than by turning and filing, that it takes the place of what we formerly called the finish cut of the lathe and all filing giving us not a theoretically perfect cylinder or perfect finish, but a much nearer perfect cylinder and finish that we obtained with the lathe. It gives us diameters to such small limits as to be called exact, but whoever insists that none but exact work be ground loses the very pith of grinding, which is economy. Modern grinding means cheaper cost for all work, many grades of work to suit many

requirements, and cheaper turning than is possible without the use of the grinding machine.

9 As a rule, the coarser the turning the greater the economy by grinding. The greatest economy is obtained by the combination of cheaper turning and grinding. It is no longer necessary to turn work smooth, straight or correctly to size and the lathe is no longer necessary as a precision tool. If it has a carriage traverse of from four to ten threads per inch, has sufficient power to carry high-speed tool cuts at that feed and is well supplied with steady rests to prevent springing of the work, it is ready for coöperation with the grinding machine. It is easier with modern grinding machines and wheels to grind off a given amount of metal when in the form of crude screw threads than in any other form, and with long work having several sizes the grinding requires less time if $\frac{1}{32}$ in. to $\frac{5}{64}$ in. is left on the diameter for grinding than if the work is turned carefully to within 0.002 in. to 0.005 in. In all cases, accurate turning increases the total cost of production and in some it makes the grinding very expensive.

10 The greatest economy is usually obtained by the combination of grinding with very rough turning. Yet there are cases where the least expensive way is to grind direct without turning, notably the greater part of crankshafts of automobiles and small gas engines and very long and slender work where turning is difficult.

11 It is not an easy matter to secure such rough turning as true economy requires in connection with grinding. Lack of knowledge of what is needed, coupled with the natural pride the workman takes in doing what tradition says is nice lathe work, prevents the grinding machine from doing what it is ready to do. Our industries are losing much while waiting for the engineer to assume the intelligent guidance of foreman and workmen who, through fear, doubt or prejudice now rob us of the great economies due to modern grinding machines. There is much yet to be learned by foremen and workmen about turning. High-speed steel makes possible much that has not as yet become common knowledge.

12 The lathe is a very old tool and foremen and workmen have known it for generations, yet I have been unable to find more than two instances where a careful study has been made of the combination of lathe work and grinding to effect the maximum saving. I have observed that lathe men have not tried to remove metal by increasing the number of cuts and using fast traverse. When urged to take coarse feeds to help the grinding machine to effect a total saving, they have invariably said that they were feeding all

that the work would stand. It has been demonstrated that three cuts with a carriage traverse of 6 per inch has produced certain work in 9 minutes that required 13 minutes to turn in one cut, because the work was so frail that with one cut no faster feed than 32 per inch could be taken. The rough-ridged surface was readily ground by taking 1 minute more than when the turning was finer, the net saving for the job being 3 minutes. In many cases the ridged surface requires no additional time.

13 In another case where the work was quite firm and was being revolved at a very high speed with a view to getting everything possible from the high-speed tool, the turning required 5 minutes and the

FIG. 1 MICROPHOTOGRAPH OF CHIPS FROM MODERN GRINDING WHEEL

Note the resemblance of these fragments to lathe chips

grinding 1 minute. A change was made in the feed of the lathe so that without revolving the work any slower it was turned in 1 minute, leaving a very crude, crooked and bad-looking piece of lathe work. The grinding then required 2 minutes, but the net time saved was 3 minutes. Did it matter how bad a looking lathe job it was if the finished work was perfect and 3 minutes was saved?

14 There is a rich field for engineers and managers in connection with the lathe and modern grinding. Recent lathe designs provide for high speed of revolution, with sufficient power, quick change to and from back gears, and sufficient rigidity to utilize to the limit

high-speed steel; but much work is not of sufficient rigidity to permit the maximum use of the tool at fast traverse and deep cuts. In addition, there are thousands of lathes of old design that will not be thrown away at once. There is, therefore, an opportunity to get much more out of present plants by cheaper turning, *because of grinding*.

15 Developments warrant the conclusion that we should no longer assume that simply because a tool is a grinding wheel it cannot remove metal and size and shape work as quickly as a steel tool.

FIG. 2 MICROPHOTOGRAPH OF FRAGMENTS FROM EMERY WHEEL

Many of the particles are melted by the heat generated in grinding

Rather, we should use the steel tool when it can be made to remove metal, size and shape work cheapest, and the grinding wheel when it excels. It is no longer to be taken as a matter of course that we can turn, plane and mill faster than we can grind. After all, the real reason we remove metal is to accomplish certain finished results, not simply to secure a certain number of pounds of chips in a given time. Before long I think all progressive engineers will understand that both the grinding wheel and the steel tool have their place for metal cutting. The old thought of abrasion must give way to the new thought of cutting.

16 While it is still true that poor wheels or good wheels poorly selected and wrongly used will still remove metal very slowly by

abrasion, it is also true that the old-fashioned milling cutter, with fine teeth cut by hand with a file, hardened but never ground, and used in the old-time slender milling machine would very slowly abrade the surface. The modern grinding wheel, used in a modern machine by a modern man, is just as surely a milling cutter as if it were made of steel.

17 The microscope reveals the fact that such a wheel cuts off chips. Fig. 1 is from a microphotograph and clearly shows the chips that are as surely cut off as those made with a steel milling cutter. The grinding wheel used was a modern one made of crystalline aluminum oxide.

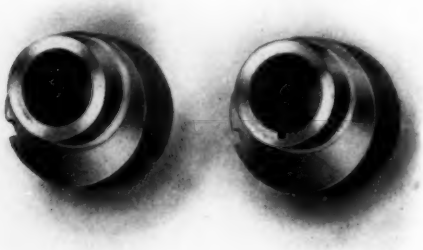


FIG. 3 FIG. 4

FIRST TWO STAGES IN THE GRINDING OF AN AUTOMOBILE CAM

18 Fig. 2 is also from a microphotograph and shows the result of the old-fashioned abrasion described by Webster as grinding to powder. Here we see the effect of great heat, the greater part of the powder being in the form of globules. This is magnified to the same extent as the other photograph and shows the vast difference between the old-time abrasion to powder and the present cutting chips. A large part of the energy put into work was wasted in heat, as shown by the very small globules in Fig. 2. The wheel used for Fig. 2 was an emery wheel like those referred to in Appleton's Cyclopædia of 1893.

19 The grinding wheel as now made is really a milling cutter with millions of cutting teeth. Although these teeth are not as large or as strong as the teeth of a steel cutter and therefore cannot cut as

deeply, yet they are capable of cutting at much greater speed. Since there are so many more of them they are capable of much more work in a given time when the nature of the work is such that a large number of these cutting points can be used simultaneously. In some cases we can use as many as two billion cutting points per minute. Eight hundred million per minute is not uncommon and four hundred million per minute is very common.

20 The modern grinding wheel, mounted in a good machine, can be used at a cutting speed of 6000 or more surface feet per minute and owing to this high speed it need not cut deeply relative to the rigidity of the work. Therefore it is able to remove metal from many forms of work more quickly than the milling cutter or the lathe tool.

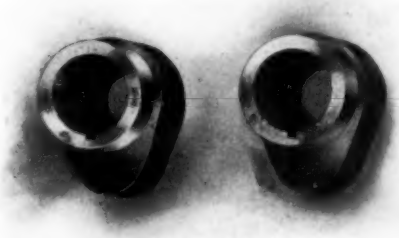


FIG. 5 FIG. 6

LAST TWO STAGES IN THE GRINDING OF AN AUTOMOBILE CAM

21 The accompanying illustrations show a notable example. Figs. 3, 4, 5 and 6 show the process of making automobile cams. An order for a hundred of these cams was received and our shop superintendent began to provide means for producing them at the lowest possible cost. It is evident that drop forgings for so few would be out of the question, as the expense of dies would make the cost of the cams prohibitive. It was therefore necessary to devise means for producing them from the bar stock. This was done by providing an eccentric chuck for the automatic screw machine. To prevent the bar from turning in the chuck while feeding forward, the spline was made the full length and a mating key was placed in the chuck. Pieces like

Fig. 3 were made in the automatic machine at the rate of 10 per hour. A keyway in the hole was made in the ordinary way, Fig. 4. These blanks were ground to rough shape, Fig. 5, at the rate of 10 per hour. The cams were then hardened and finished ground to Fig. 6 at the rate of 40 per hour. It should be clear that such a cam could not be milled to shape from the blank in nearly so short a time with the milling cutter. When manufacturing such cams in large numbers drop forgings would be used, and here again the grinding wheel is quicker than the milling cutter.

22 Another case where the grinding machine can accomplish the results desired in less time than the lathe is that of the pins and bearings of the automobile crankshaft. The results desired are as follows:

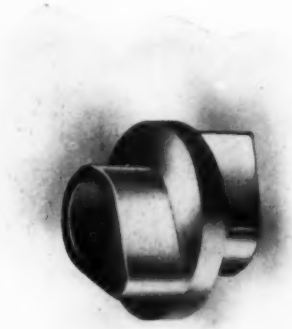


FIG. 7 DOUBLE CAM GROUND FROM ROUGH STOCK 2 IN. IN DIAMETER

Five bearings, all round within 0.00025 in.; the axis of all parallel and exactly in line; all of the right length within 0.004 in.; distance between bearings within 0.004 in.; accumulated error not over 0.008 in. Four crank pins, all round within 0.00025 in.; the axis of all exactly parallel; all to length within 0.004 in.; all parallel with the bearings; all within 0.005 in. of the same plane; all of correct throw, within 0.010 in.; overall length, accumulated error not over 0.008 in.; all fillets correct radius and exactly concentric with the bearings and pins; all bearings and pins straight within 0.00025 in.; and all a good, smooth surface.

23 In the case of cranks designed with clearance for the arms of the cranks, as shown in Fig. 8, the width of the wheel is identical with

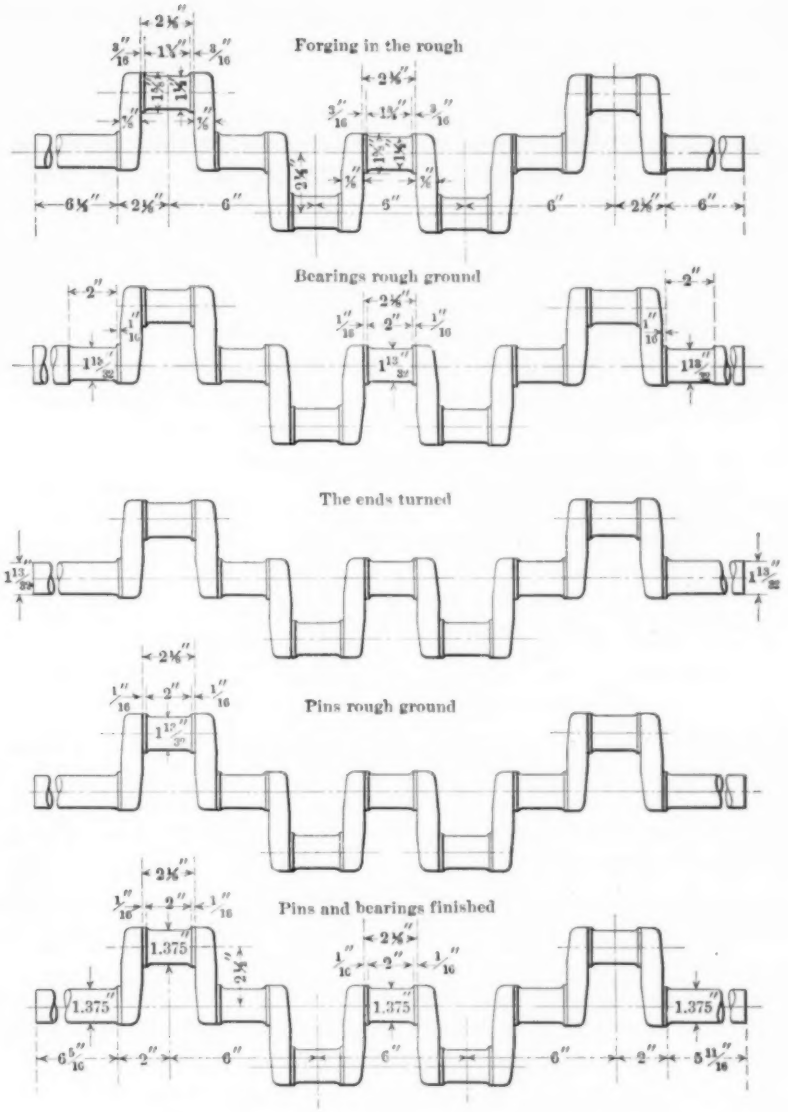


FIG. 8 STAGES IN THE GRINDING OF AN AUTOMOBILE CRANKSHAFT

the required length of the pins and bearings, so that no measuring or setting of the tool is necessary for cutting to length. The act of grinding cuts the bearing or pin the right length and forms the fillets.

The location of the pins and bearings within the small limits allowed is accompanied by a massive index bar, so that the workman does no measuring whatever for location of bearings or pins. The entire time of handling and producing these five bearings and four pins from the rough forging to the nicely-sized and finished condition is 85 minutes. It is clear that when all the conditions of the finished work are considered the grinding wheel and machine have removed metal faster than the lathe. Again, it is not simply a case of removing pounds of metal per hour, but the removal of it in such a manner as to accomplish certain results in the least time.

24 The ends of these shafts beyond the bearings are turned before grinding. The entire list of operations to make a finished shaft from the forging is as follows:

Cut off ends and center	6 minutes
Rough grind bearings	15 minutes
Turn ends	8 minutes
Rough grind pins	20 minutes
Finish grind pins	20 minutes
Finish grind bearings and ends	25 minutes
Square ends	6 minutes
Total time	100 minutes

A little time could be saved if it were practical to secure forgings with pins and bearings $1\frac{5}{8}$ in. in diameter over their entire length instead of with the depression to $1\frac{1}{2}$ in. between shoulders, as the wheel can be forced more rapidly when the face has the same amount of work to do as the fillets. Here again tradition is strong and difficult to change at once, because the depression is better for those who turn the work. A little coöperation would save on dies and time in grinding.

25 There are hundreds of other cases where the grinding wheel is used to remove metal in a more economical manner than with steel-cutting tools, some of which are shown in Figs. 9 to 19.

26 Automatic grinding is a late development in the field. Certain work of which large numbers of pieces are made is ground by wholly automatic means. The work is conveyed to the machine by gravity in a hopper or shute and is chucked, ground and delivered to the receptacle. In a case where formerly, at piece work, 300 per day were ground, the automatic machine grinds 4 in a single minute, about 2300 per day.

27 When the knowledge of grinding becomes more common and the opposition to increased production on the part of the workmen shall have been more nearly overcome, the field will be still more extended. It is worthy of more systematic coöperation and if we get together we will be rewarded with success. The engineer is the one who by education and training is best fitted to take up the important question of the field for grinding.

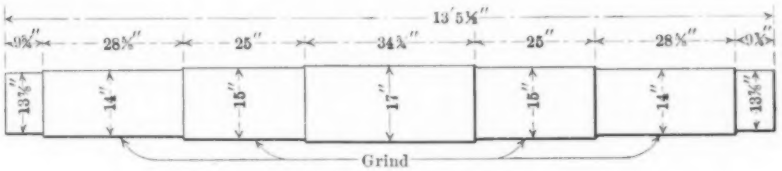


FIG. 9 ENGINE SHAFT—HAMMERED FORGING

Weight, 8000 lbs.; stock removed, 0.025 in.; limit, 0.001 in.; time, 6 hr. (8 hr. including handling)

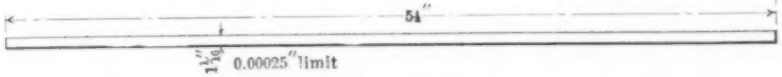


FIG. 10. SHAFT 0.30 CARBON STEEL

Stock removed, $\frac{1}{16}$ in.; limit, as noted; time, 1 hr. (including setting up)

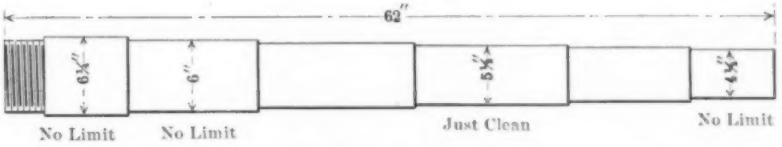


FIG. 11 LATHE SPINDLE—CRUCIBLE STEEL, HARDENED

Stock removed, 0.035 in.; limits, as noted; time, 1½ pieces per hr.

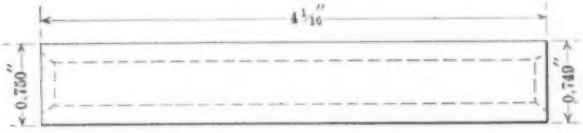


FIG. 12 PISTON PIN—0.15 CARBON STEEL, HARDENED

Stock removed, 0.015 in.; limit, 0.0005 in.; time, 60 pieces per hr.

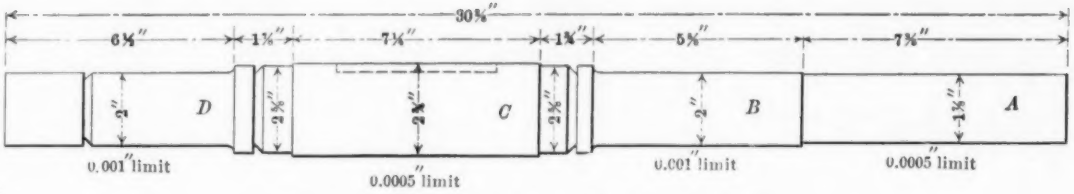


FIG. 13 ARMATURE SHAFT—0.30 CARBON STEEL

Stock removed, $\frac{3}{64}$ in.; limits, as noted; time, 3 pieces per hr.

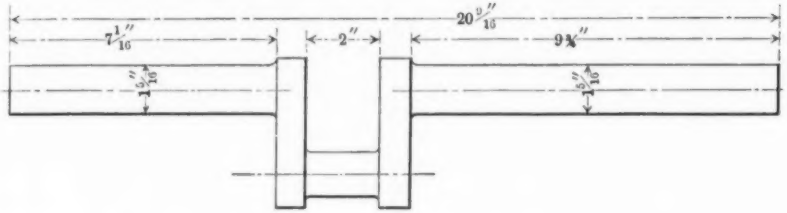


FIG. 14 CRANKSHAFT—0.45 CARBON STEEL

Grind bearings only; stock removed, 0.015 in.; limit, 0.0005 in.; time, 50 in 7 hr. 15 min.

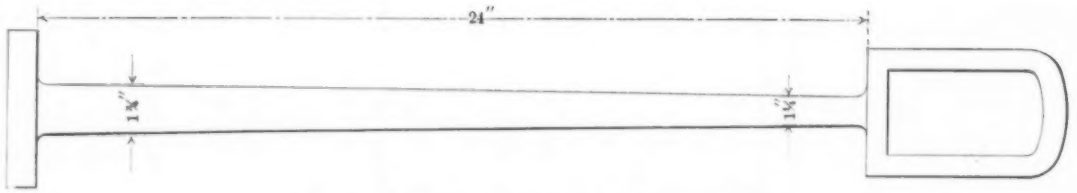


FIG. 15 CONNECTING ROD—0.30 CARBON STEEL

Stock removed, 0.008 in.; limit, just cleaned; time, 25 pieces per hr.

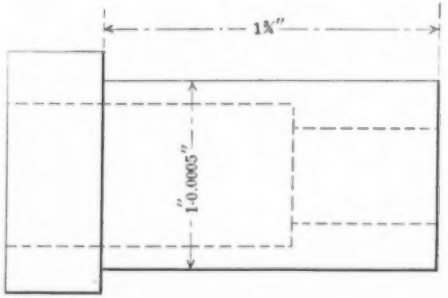


FIG. 16 BUSHING—CAST IRON

Stock removed, 0.010 in.; limit as noted; time, 45 pieces per hr.

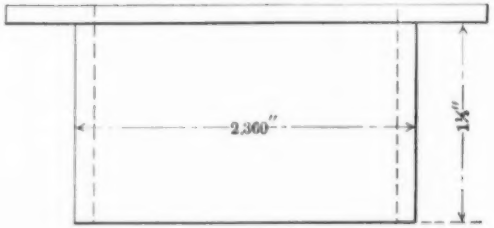


FIG. 17 BUSHING—PRESSED STEEL

Stock removed, 0.025 in.; limit 0.0005 in.; time 60 pieces per hr.

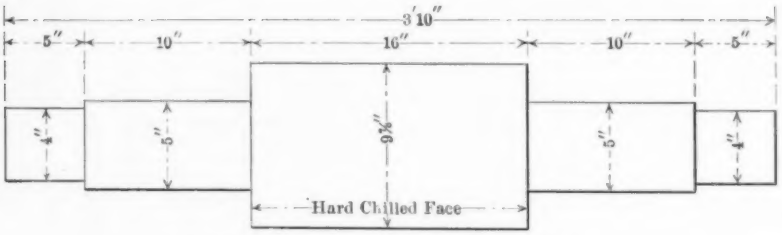


FIG. 18 CHILLED ROLL—CHILLED IRON

Stock removed, ⅜ in.; time roll face, 2½ hr.; previous lathe time 12 hr.

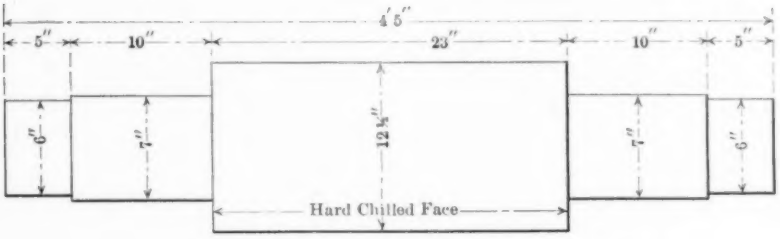


FIG. 19 CHILLED ROLL—CHILLED IRON

Stock removed, ½ in.; time roll face, 7½ hr.; journals and ends, 3½ hr.; total, 10½ hr.; lathe time for same work, 23 hr.

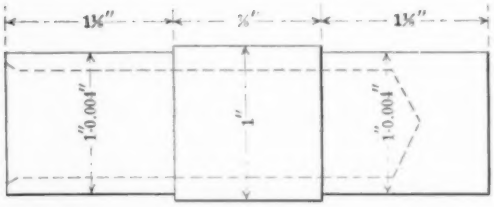


FIG. 20 PISTON PIN—MACHINE STEEL, HARDENED

Stock removed, 0.015 in.; limit, 0.0005 in.; time, 25 pieces per hr.

PRECISION GRINDING

By W. A. Viall, Providence, R. I.

Member of the Society

Grinding is an art rather than an exact mechanical operation. It is an art of such recent growth that relatively little is known about it or its possibilities. In the development of the grinding machine from the early beginning, as described in the historical article in Machinery of July 1910, to the present well-known makes of universal and plain grinding machines, the successive steps that have been taken toward reaching stability and convenience in the machine form interesting chapters of mechanical history, since they show, as well as any class of machines, the tendency of the times.

2 In speaking of grinding as an art I mean that it contains elements in which the judgment and experience of the operator count for a great deal. While in a general way the manufacturer or the skilled operator is able to give instructions for the running of the machines, yet conditions arise which make it necessary to vary from these instructions in order to obtain the best results. To instruct an operator to use a given wheel and speed would make it possible for him to obtain any one of the three results. When ground with a wheel surface that is not true a piece looks as though it had been gouged upon a grindstone, while with a wheel surface that is true it gives a dull finish and shows the wheel marks. The latter is what we consider commercial grinding. When this same wheel has been run so that the points of the abrasive become somewhat dull, we obtain a highly-finished surface. All these results are possible with the same wheel under different conditions.

3 Most of us are interested in two classes of grinding, One is the occasional grinding such as we find in the tool room and in the shop

The American Society of Mechanical Engineers, 29 West 39th Street, New York. All papers are subject to revision.

where one or two pieces of a kind are made and where accurate fits are demanded. The second is the manufacturer's problem where not only must the nicest accuracy be obtained but where the rate of production is an important consideration. In the first case the question of cost does not enter so deeply into the problem, although it is always to be considered; and one machine, specially designed to do a certain class of work, is often compelled to answer the necessities for work to which it is not well suited. In the second case, however, the best results as to efficiency and production are obtained by having a machine of the proper size. It must be understood from the first that whether the machine is large or small it must be sufficiently heavy and stable enough to do the work it is called upon to do and it must be so designed that it can readily be operated. This latter element of convenience must be provided for even more carefully than in many other classes of tools, because much of the work done in the grinding machine is of such a character that the operations of putting in and taking out consume almost as much time as the grinding. Moreover, a grinding machine must have sufficient rigidity to preserve its alignment, which must be of a high grade from the first. Unless the machine is capable of producing true work its value is lost, for the grinding machine must not only finish work but also rectify it to a degree of accuracy that we cannot in reason look to a lathe or other type of machine to furnish commercially.

4 The principles of grinding, in the main, are not difficult to grasp, and the time that would be required of the ordinary chief operator in grasping them is not excessive. But the work does require such attention and knowledge of the results that can be obtained, coupled with the skill acquired by experience, as to class it with the Arts. In the early days it seemed quite necessary that for every different piece of work we should have a different wheel. Later it was found that a given wheel would give satisfactory results on various kinds of work by varying the speed of the wheel, the speed at which the work was run, or the feed of the work, so that one wheel answered a great variety of purposes. There have been changes in abrasives and we are getting today a far better quality of wheel than was possible some years ago. The grading of wheels has very much improved, and although in the writer's opinion it is not possible to obtain an absolute grading, this element has been reduced to such a nicety that it need not be taken largely into account by the average operator.

5 The first use of the grinding machine as we know it today

was to correct slight errors that were impossible of eradication by means of the file and emery cloth. Today the grinding machine rectifies these errors and in addition finishes work for appearance and fit in a relatively cheap manner.

6 After the proper machine has been selected, the choice of wheels requires some specialized knowledge which the makers of machines and wheels are in a position to furnish to an extent that many of the users of machine tools are probably not aware. When the proper wheels and gradings are once established for a given line of work their subsequent use is very easy.

7 The question of speeds and feeds is also the result of experience, and suggestions from the manufacturers will help users to a great extent in obtaining satisfactory results. The cutting operation of the wheel was well shown in an illustrated article by Messrs. Gribben and Warman[1] where the microscopic photographs showed that the chips somewhat resembled those made by a lathe tool. It is only under proper conditions, however, that these results can be obtained. The wheels must be true and they must not be forced into the work to too great an extent, for this produces a torn effect upon the work, which is to be avoided.

8 In considering a piece of work to be done, first of all the question arises as to the size and the limits suitable for the purpose for which it is intended. Table 1 gives the limits used at the Brown & Sharpe Mfg. Co.'s works for varying conditions. There are special cases where it may be necessary to increase or to decrease these limits, and this table is not offered as the final word but as a guide towards selection.

9 The second necessity is that sizes should be established to which the work should be rough turned ready for the grinding room. In our works, as in all factories, the aim is to produce the desired results as cheaply as possible. Our desired ends have been accuracy and nicety of finish where the parts ground are for fits, and nicety of finish where no fit is required. To do this work as cheaply as possible we believe that it is economical to turn the pieces to about the sizes indicated in Table 2. It will be noted that we allow from 0.008 in. to 0.012 in. in diameter, an amount easily obtained by the ordinary class of lathe help. In order to make this work as easy as possible for the lathe department, we furnish the limit gage shown in the sketch. We are aware that practice varies on this point, and we have thoroughly

[1] American Machinist, July 2. 1903.

TABLE 1 GRINDING LIMITS FOR CYLINDRICAL PIECES[1]

AS ADOPTED BY BROWN AND SHARPE MFG. CO.,

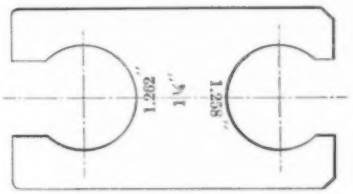
RUNNING FITS—ORDINARY SPEED		
To ½-in. diameter, inc.	0.00025 to 0.00075	Small
To 1 -in. diameter, inc.	0.00075 to 0.0015	Small
To 2 -in. diameter, inc.	0.0015 to 0.0025	Small
To 3½-in. diameter, inc.	0.0025 to 0.0035	Small
To 6 -in. diameter, inc.	0.0035 to 0.005	Small
RUNNING FITS—HIGH SPEED, HEAVY PRESSURE AND ROCKER SHAFTS		
To ½-in. diameter, inc.	0.0005 to 0.001	Small
To 1 -in. diameter, inc.	0.001 to 0.002	Small
To 2 -in. diameter, inc.	0.002 to 0.003	Small
To 3½-in. diameter, inc.	0.003 to 0.0045	Small
To 6 -in. diameter, inc.	0.0045 to 0.0065	Small
SLIDING FITS		
To ½-in. diameter, inc.	0.00025 to 0.0005	Small
To 1 -in. diameter, inc.	0.0005 to 0.001	Small
To 2 -in. diameter, inc.	0.001 to 0.002	Small
To 3½-in. diameter, inc.	0.002 to 0.0035	Small
To 6 -in. diameter, inc.	0.003 to 0.005	Small
STANDARD FITS		
To ½-in. diameter, inc.	Standard to 0.00025	Small
To 1 -in. diameter, inc.	Standard to 0.0005	Small
To 2 -in. diameter, inc.	Standard to 0.001	Small
To 3½-in. diameter, inc.	Standard to 0.0015	Small
To 6 -in. diameter, inc.	Standard to 0.002	Small
DRIVING FITS—FOR SUCH PIECES AS ARE REQUIRED TO BE READILY TAKEN APART		
To ½-in. diameter, inc.	Standard to 0.00025	Large
To 1 -in. diameter, inc.	0.00025 to 0.0005	Large
To 2 -in. diameter, inc.	0.0005 to 0.00075	Large
To 3½-in. diameter, inc.	0.00075 to 0.001	Large
To 6 -in. diameter, inc.	0.001 to 0.0015	Large
To ½-in. diameter, inc.	0.0005 to 0.001	Large
DRIVING FITS		
To 1 -in. diameter, inc.	0.001 to 0.002	Large
To 2 -in. diameter, inc.	0.002 to 0.003	Large
To 3½-in. diameter, inc.	0.003 to 0.004	Large
To 6 -in. diameter, inc.	0.004 to 0.005	Large
To ½-in. diameter, inc.	0.00075 to 0.0015	Large
FORCING FITS		
To 1 -in. diameter, inc.	0.0015 to 0.0025	Large
To 2 -in. diameter, inc.	0.0025 to 0.004	Large
To 3½-in. diameter, inc.	0.004 to 0.006	Large
To 6 -in. diameter, inc.	0.006 to 0.009	Large
To ½-in. diameter, inc.	0.00025 to 0.0005	Large
SHRINKING FITS—FOR PIECES TO TAKE HARDENED SHELLS ⅛-IN. THICK AND LESS		
To 1 -in. diameter, inc.	0.0005 to 0.001	Large
To 2 -in. diameter, inc.	0.001 to 0.0015	Large
To 3½-in. diameter, inc.	0.0015 to 0.002	Large
To 6 -in. diameter, inc.	0.002 to 0.003	Large
To ½-in. diameter, inc.	0.0005 to 0.001	Large
SHRINKING FITS—FOR PIECES TO TAKE SHELLS ETC., HAVING A THICKNESS OF MORE THAN ⅛-IN.		
To 1 -in. diameter, inc.	0.001 to 0.0025	Large
To 2 -in. diameter, inc.	0.0025 to 0.0035	Large
To 3½-in. diameter, inc.	0.0035 to 0.005	Large
To 6 -in. diameter, inc.	0.005 to 0.007	Large
To ½-in. diameter, inc.	Standard to 0.0005	Large
GRINDING LIMITS FOR HOLES		
To 1 -in. diameter, inc.	Standard to 0.00075	Large
To 2 -in. diameter, inc.	Standard to 0.001	Large
To 3½-in. diameter, inc.	Standard to 0.0015	Large
To 6 -in. diameter, inc.	Standard to 0.002	Large
To 12-in. diameter, inc.	Standard to 0.0025	Large

[1] The limits given in the table can be recommended for use in the manufacture of machine parts to produce satisfactory commercial work. These limits should be followed under ordinary conditions. Special cases should always be considered, as it may be desirable to vary slightly from the tables

endeavored to try out the plan of allowing correct limits, but we have found it fully practicable to hold the lathe to the limits given. By so doing we obtain the finished product free from all tool marks and at what we believe is the minimum cost.

10 Figs. 1 to 6 show some samples of commercial grinding taken from actual practice for the purpose of giving an idea of what can be done in a commercial way, as well as to give some definite data as to speeds, feeds, etc. While it is perhaps not possible to give a rule that

TABLE 3 LIMIT GAGES FOR LATHE WORK



Size	Not Go On	Go On	Size	Not Go On	Go On	Size	Not Go On	Go On
	Inches			Inches			Inches	
⅜	0.383	0.387	15/16	0.9455	0.9495	1½	1.508	1.512
7/16	0.4455	0.4495	1	1.008	1.012	1 9/16	1.5705	1.5745
½	0.508	0.512	1 1/16	1.0705	1.0745	1⅝	1.633	1.637
9/16	0.5705	0.5745	1⅛	1.133	1.137	1 11/16	1.6955	1.6995
⅝	0.633	0.637	1 3/16	1.1955	1.1995	1¾	1.758	1.762
11/16	0.6955	0.6995	1¼	1.258	1.262	1 13/16	1.8205	1.8245
¾	0.758	0.762	1 5/16	1.3205	1.3245	1⅞	1.883	1.887
13/16	0.8205	0.8245	1⅜	1.383	1.387	1 15/16	1.9455	1.9495
⅞	0.883	0.887	1 7/16	1.4455	1.4495	2	2.008	2.012

will fit all work, these plates should suggest ideas that will help in producing the work as well and as cheaply as this has been done in the cases shown. When enough pieces of any one kind are to be made it is possible to specialize to a higher degree than can be done in the general run of work, and better results may be obtained than are shown here.

11 The examples of commercial grinding given in Figs. 1 to 6 illustrate what is being done under actual working conditions in commercial work on the variety of pieces indicated, which are of various materials, both soft and hard. A reversal of the usual rule, where economy is

TABLE 3 EXAMPLES OF COMMERCIAL GRINDING

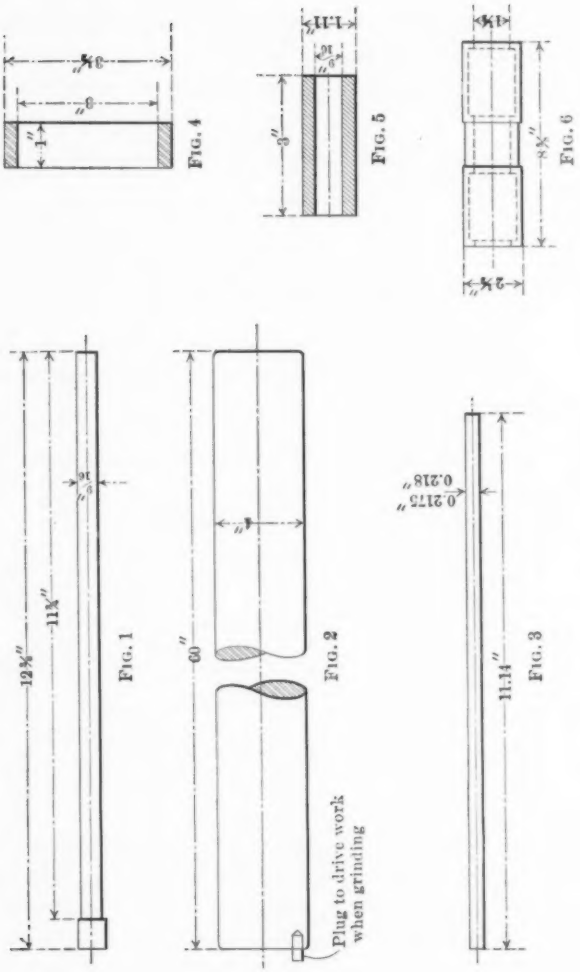


Fig. No.	1	2	3	4		5	6	
Material	Soft machinery steel	Machinery steel	Machinery steel, case-hardened	Machinery steel, case-hardened		Cast iron	Bearing bronze	
Part Ground	External	External	External	Internal		External	External	
Machine Used	No. 11 Plain	No. 28 Plain	No. 11 Plain	No. 1 Universal (Special)		No. 11 Plain	No. 14 Plain	
Wheel Used	Monarch, 12 in. × 1 in. Corundum, No. 46, grade 2½	Norton, 24 in. × 2 in. Alundum, No. 3846, grade K	Norton, 12 in. × ½ in Alundum, No. 36, grade 5, elastic	Norton, 2½ in. × 2 in.; Alundum, No. 5, grade 2½ elastic		American, 12 in × 1 in., Corundum, No. 46, grade K	Abrasive, 18 in. × 1½ in.,Corundum, No. 60 grade L	
Periphery Speed of Work, Ft. per Min.	35	35 roughing; 60 finishing	35	100		55	75	
Travel of Work, In. per Min.	96	48 roughing; 30 finishing	13	By hand		37	30	
Periphery Speed of Wheel, Ft. per Min.	7000	6000	5500 to 6000	5500		6500	6000	
Amount of Stock Removed, Diameter.	0.012 in. roughing, 0.005 in. finishing	0.025 in. roughing, 0.005 in. finishing.	0.005 in. roughing; 0.001 in. finishing	0.018 in. to 0.020 in.	0.010 in. to 0.010 in.	0.020 in. to 0.025 in.	0.012 in. to 0.015 in.	
Number of Pieces Completed per Hr.	13	3.5	15	16	20	54	32 1 man	59 2 men*
Required Limit	Standard to 0.00025 in. small	Standard to 0.001 in. small	Standard to 0.0005 in. small	Standard to 0.0005 in. large		Standard to 0.0005 in. small	Standard to 0.0005 in. small	
In Lots of	100	50	500	200		200	100	
Remarks	21 roughed; 35 finished per hr. Handled twice	7 roughed; 7 finished per hr. Handled w ice	Handled twice roughing and twice for finishing				*A man operates the machine and a helper puts the work on and off the arbor	

gained by having one man operate more than one machine, is shown in Fig. 6, where work is most economically produced by using two men to run one machine, that is, having one man to operate it and a helper to drive the work on and off the arbor. All other data are based on one man to a machine.

12 These pieces passed inspection within the limits given. The average loss from work of this class coming below the required limit or being otherwise spoiled is less than $\frac{1}{4}$ of 1 per cent in our grinding department.

13 Figs. 7 to 13 are each notated to show the peculiar features that exist in the work, together with the data that may be of help in deciding upon other work of this class.

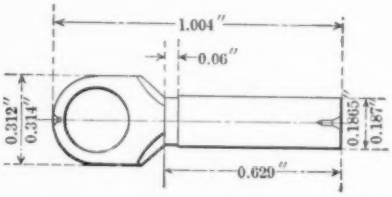


FIG. 7 SEWING-MACHINE PLUNGER—CASE HARDENED

This piece is ground at the rate of 145 per hour. Only a small amount 0.006 in., is taken off to prevent grinding below the case-hardened surface. Ground on No. 11 plain grinding machine. As this piece is only about 1 in. long it is quite difficult to handle, and this somewhat reduces the output.

An elastic wheel 36, grade 5 is used; speed of wheel, about 6000 ft. per min; speed of work, about 35 ft. per min.

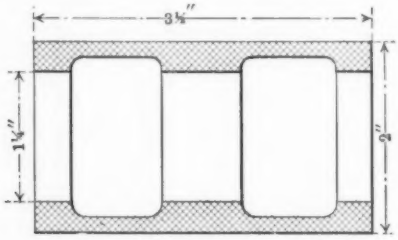


FIG. 8 BRONZE BUSHING

These bushings are ground at the rate of 30 per hour. Ground on No. 12 or No. 14 Plain Grinding Machine.

About 0.020 in. of stock is removed from the diameter. A 54 grade M American wheel is used; speed of emery wheel, about 6500 ft. per min.; speed of work, about 70 ft. per min.

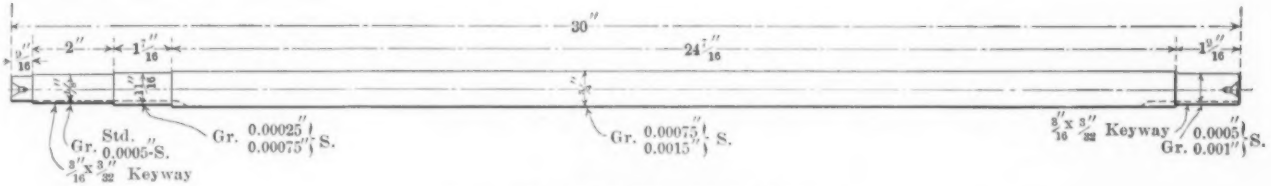


FIG. 9 SHAFT OF MACHINERY STEEL

These shafts can be finished down to size at the rate of 3 per hour. Between 0 010 in and 0.015 in. of stock is removed from the diameter. A Norton wheel, 3836 combination L, is used.

Speed of emery wheel, about 7000 ft. per min.

Speed of work, about 55 ft. per min. Ground on No. 11 Plain Grinding Machine.

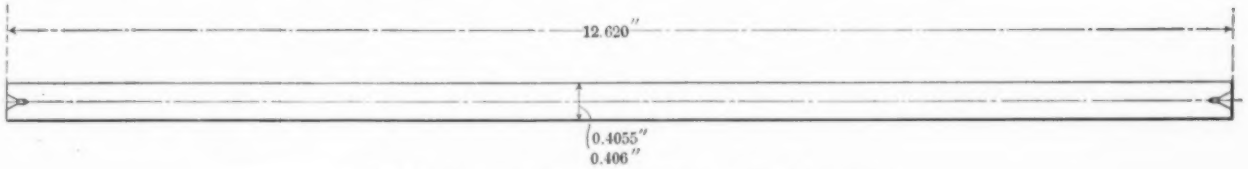


FIG. 10 SEWING-MACHINE SHAFT—CASE HARDENED

These pieces are ground at the rate of 15 per hour. They are turned end for end for dogging in both the roughing and finishing operation; thus they are handled four times to complete. Only about 0.006 in. is left for grinding to prevent grinding under the case-hardened surface. These shafts are rough ground where there is so small an amount of stock for the purpose of breaking the scale the entire length before finishing. They are held to a limit gage ("Go on" and "Not go on"), and must be ground straight. An elastic wheel 36 grade 5 is used.

They are run through in lots of 500.

Speed of wheel, about 6000 ft. per min.

Speed of work, between 30 and 35 ft. per min.

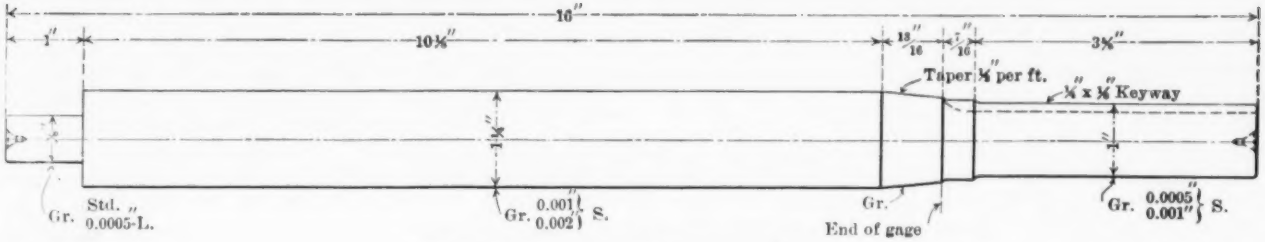


FIG. 11 SHAFT OF MACHINERY STEEL

This is a very difficult shaft to grind on account of the small diameter at one end, which gives a very poor support for grinding the larger diameters. It therefore takes about 1½ hr. to finish one shaft.

The $2\frac{5}{16}$-in. diameter is roughed out first so that a back rest can be used. Each shaft is handled 6 times before it is finished, and from 0.015 in. to 0.018 in. of stock is taken off.

Speed of wheel, about 7000 ft. per min.

Speed of work about 45 ft. per min. Ground on No. 12 or No. 14 Plain Grinding Machine.

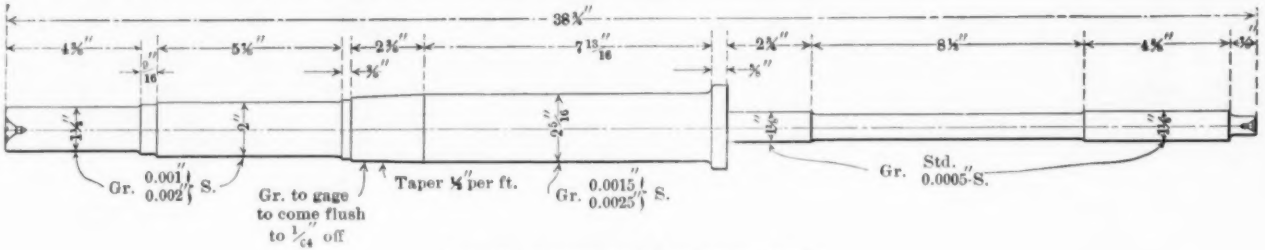


FIG. 12 SHAFT OF MACHINERY STEEL

These shafts are ground at the rate of about 5 per hr. They cannot stand heavy cuts on account of having a small diameter at one end. The taper is ground to a gage and must be concentric. Each piece is handled four times before it is finished.

Speed of emery wheel, about 7000 ft. per min.

Speed of work, about 65 ft. per min.

Ground on No. 12 Plain Grinding Machine.

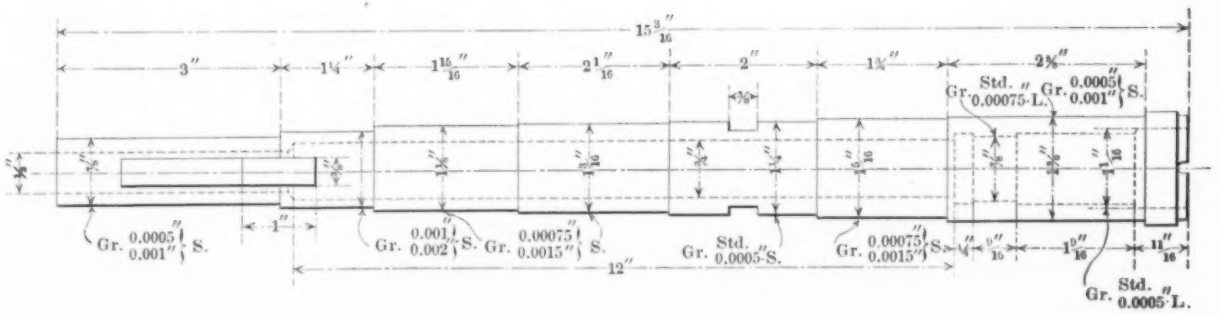


FIG. 13 SPINDLE OF UNION DRAWN STEEL—CASE HARDENED

This spindle is ground both externally and internally. It is rough ground and then finish ground all over. A Monarch wheel 46-2¼ or a Norton wheel 3846 grade K is used. A very fine finish is produced. Note hole running entire length of spindle, also where cut away near small end and near middle, all of which adds to the problem of grinding. One man grinds these spindles in lots of 50 in a little less than ½ hr. each. Actual time 50, in 24 hr. From 0.015 in. to 0.025 in. of stock is left on diameter for grinding and 0.003 in. or 0.004 in. is left for finish grinding. These spindles are ground internally on two diameters to a very close limit. These two holes must be exactly concentric and are therefore ground at one setting, at the rate of 3 per hr. Each spindle is handled 12 times before completion.

Ground on a No. 11 Plain Grinding Machine, and on a No. 2 Universal Machine for internal grinding.

MODERN GRINDING METHODS

By B. M. W. Hanson, Hartford, Conn.

Member of the Society

One of the oldest, perhaps the oldest, means for reducing material for the purpose of giving it the desired shape, is by grinding. Our ancestors ground their stone axes and arrow points against a rock, by rubbing them back and forth. The next advance in grinding was probably the revolving of a stone on an axle turned by a crank. It was soon discovered that by having water running on a stone, the grinding could be done faster. This discovery was probably made by accident, since at that time nobody would have thought of the reason so long as results were obtained.

2 Grinding had then advanced to a point where the grinding member revolved in a fixed position, but the piece to be ground was held in the hands of the operator, and by manipulating it at different angles to the grinding surface, a shape was obtained which met the requirements reasonably well. The art seems to have remained at this stage for centuries and not until the lathe and other machine tools had been in use for a long time was it thought to hold the piece of work in a fixed position against a revolving grinding member also having a fixed position.

3 The grinding machine as now used is of comparatively recent origin, within the memory of men now living. The first grinding machines suggestive of modern methods of grinding were made in England and America, but it is in America that they have reached their highest development.

4 The invention of emery wheels made it possible to make fairly rapid progress with grinding processes. At first very little work was ground which could be machined and filed. The process of grinding was confined to pieces of hardened steel, but after awhile it was discovered that unhardened pieces could be machined and finished more

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accurately and cheaply by grinding process than by finish turning and filing.

5 The grinding machine for cylindrical surfaces was developed to meet all strains and forces due to the cutting power of the shellac emery wheel; but when corundum and carborundum wheels were put in use it was found that the machinery was not quite strong and heavy enough to resist their cutting power or to resist the vibration. Within the last few years great improvements have been made not only in the cutting quality of grinding wheels, but in the design of the machines themselves; in fact, grinding machinery has become a formidable competitor of the lathe and milling machine and seems to be quite up to the cutting capacity of the wheels.

6 The designers of grinding machinery have had a good many problems to solve. Different materials require different speeds and on the modern grinding machine there must be various speeds for the grinding member as well as for the traverse movement of the work; and for the revolution of the work in the case of the cylindrical grinder. Machines must be designed with water pumps, and the working parts must be protected from water as well as from the grit which comes from the grinding wheel. The grinding member usually moves at a high rate of speed and must have carefully designed bearings which will run freely, yet not allow any back lash, as true surfaces can only be obtained when the work and the reducing member move against each other in fixed positions. Most of these difficulties have been met and further refinements are constantly being made. I will give a few illustrations of such improvements further on.

7 The grinding machines now used can be divided into two large groups; machines for cylindrical grinding and machines for grinding flat surfaces. Cylindrical grinders are well known and have been highly developed by four machine-tool builders in this country. The other style of grinder, the surface grinder, is best known as a planer type machine, with a wheel grinding on its periphery, and fed across the surface in much the same manner as a tool is fed across the surface on a planer or shaper. Another type is the vertical surface grinder with a cup-shaped wheel working in much the same manner as an end mill on a vertical milling machine.

8 In doing work on lathes or milling machines, it is comparatively easy to reproduce several pieces to the same dimensions by adjusting the machine to a size. This is possible because the reducing member, which is the turning tool, will resist wear for a considerable length of time without making any difference in the size of the work.

With grinding machinery this is more difficult since the reducing member is constantly wearing away at a rapid rate. For very close work it is necessary to readjust the machine for every piece to be ground, which of course requires skill and time.

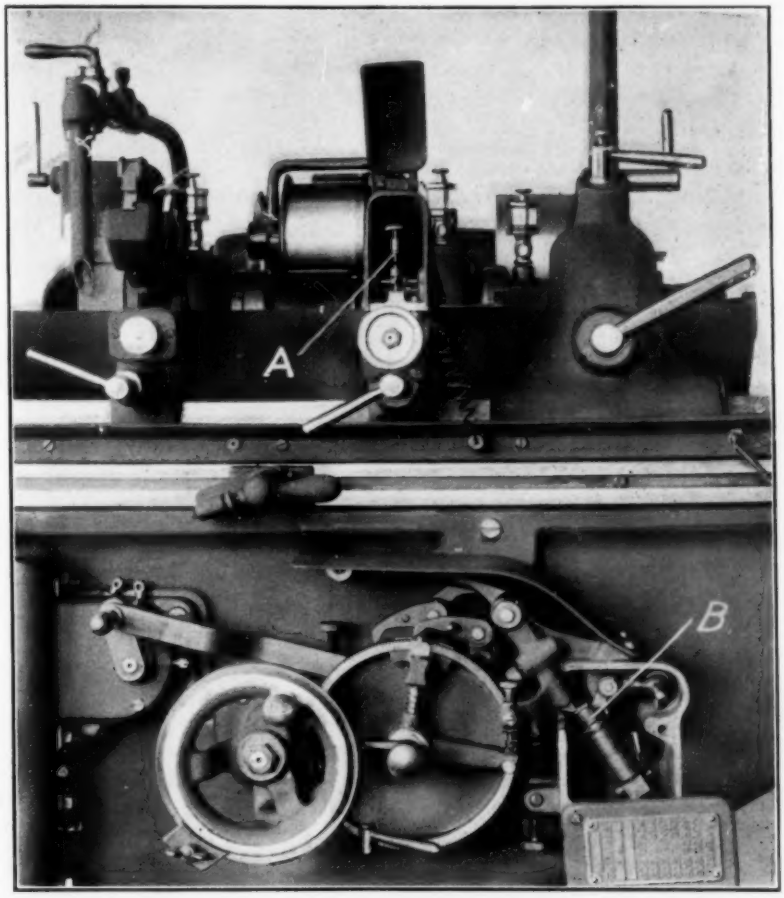

FIG. 1 VIEW SHOWING DEVICE (AT A) FOR CYLINDRICAL GRINDER, AND MAGNET (AT B) THROUGH THE OPERATION OF WHICH THE FEED IS CONTROLLED

9 The devices shown in Fig. 1 are of such construction that they control the size of the work, no matter how much the reducing member wears way. When the work has reached the desired size, which can be predetermined by suitable adjustments, the machine will auto-

matically throw out the feed and new pieces can be put in, one after another, and these will be automatically ground to practically the same diameter, say within one-quarter of a thousandth of an inch.

10 This result is brought about by controlling the feed of the reducing member electrically. The mechanism of the controlling device is shown in Fig. 2. The lever *A* carries a smooth-pointed diamond which bears against the work *W* at *a* and at its other end is the point *b* for electrical contact. There is a second lever *C* with contact points at *c*, and a contact point *d* is attached to the frame. As the diameter of the work is reduced the long arm of lever *A* drops until point *b* touches the contact point at *c*, which, through an electrical connection changes the feed of the wheel and causes it to move against the work at a slower rate. When the work has been reduced to size,

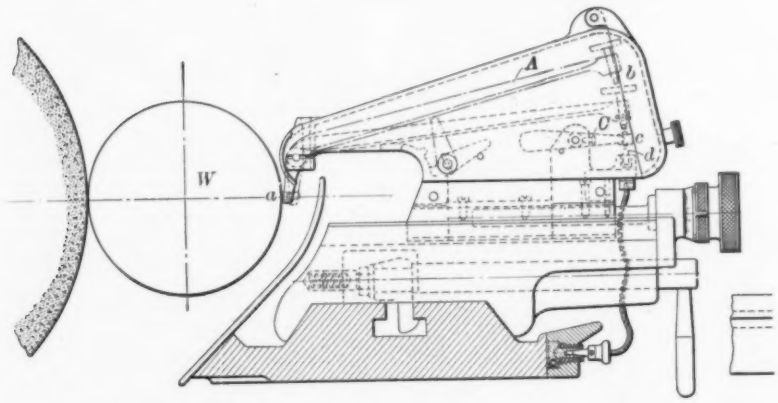

FIG. 2 VIEW SHOWING MECHANISM OF SIZING DEVICE

lever *A* drops still further, carrying with it lever *C*, until an electrical connection is established between points *c* and *d* which throws out the feed.

11 It will easily be seen that an operator can manipulate more than one of these machines and that by their use less skill is required to get uniformity of size. In this design the size of the work is controlled by contact with the work itself, which is the preferable way, but the same results could be obtained by contact with the reducing member. This, however, would be more difficult because of the coarseness of the reducing member and its ability to wear away the contact point faster than does the work.

12 Another recent device is the back rest, shown in Fig. 3. It has been found necessary to support the work as rigidly as possible

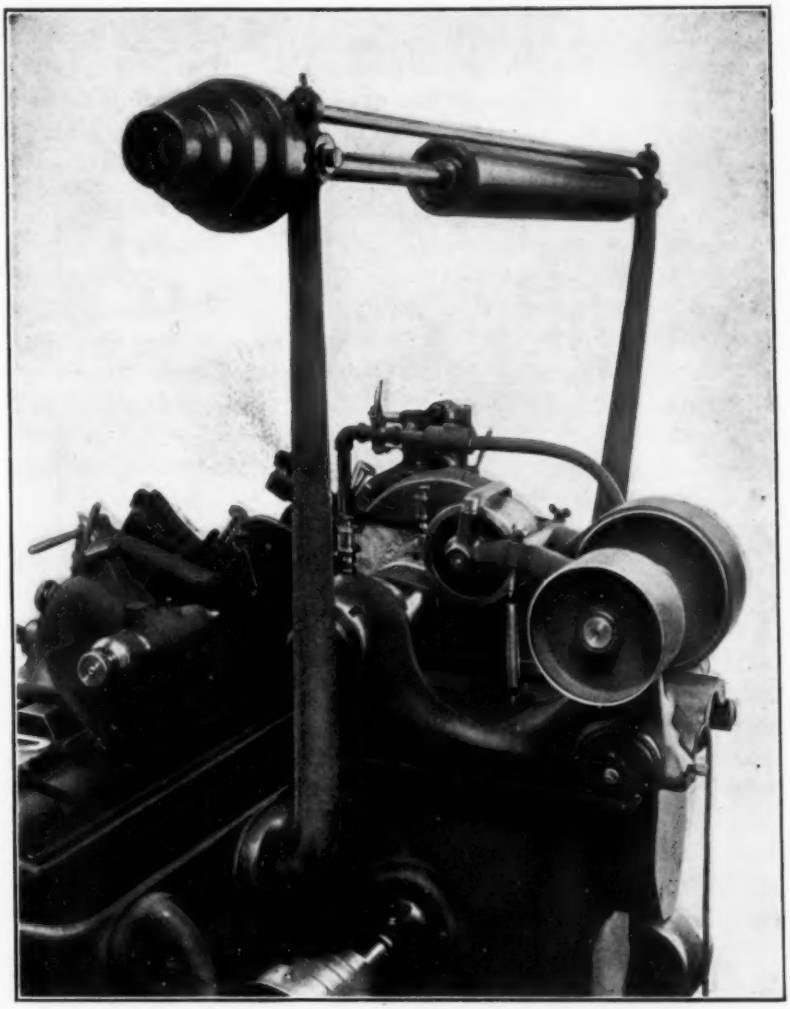

FIG. 3 VIEW SHOWING BACK REST IN PLACE; ALSO OVERHEAD DRUM, WHICH IS MADE AN INTEGRAL PART OF THE MACHINE

throughout its length, but as the work is constantly being reduced in diameter, the back rest must be kept in contact with the work either

by hand or automatically, and hand adjustment requires considerable skill. In the device shown it is accomplished automatically, the back rest advancing at exactly the same rate that the diameter of the work is reduced by the wheel; and as it advances, the back rest member is locked solid, making it impossible to spring it by the wheel pressing against it when traveling across.

13 This view also shows the overhead drum, which is made an integral part of the machine. The main drive for the machine is

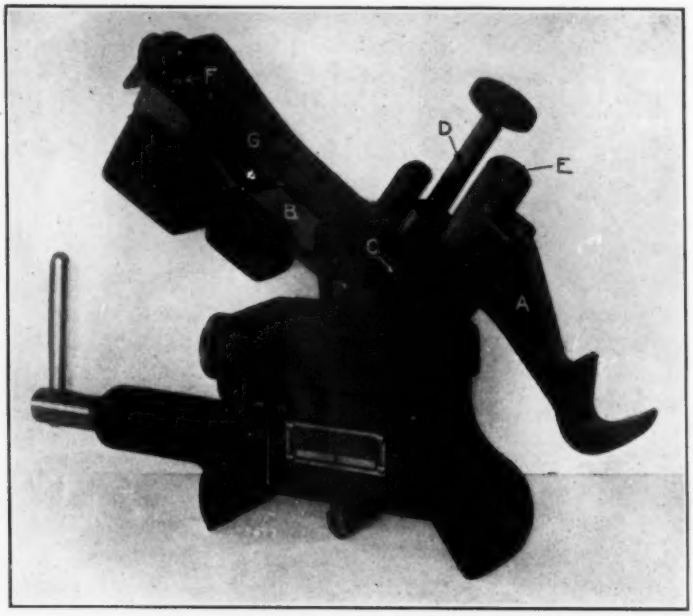

FIG. 4 BACK REST, DESIGNED TO FOLLOW THE WORK AS IT REDUCES IN DIAMETER AND TO LOCK AUTOMATICALLY AGAINST THE PRESSURE OF THE WHEEL

by single belt to a short shaft at the base, from which the drives for the wheel and the drum are belted. This arrangement avoids a complicated overhead countershaft and enables the operator to change the speeds and manipulate the various mechanisms with ease.

14 The operation of the back rest will be understood from Fig. 4. The arm *A* which supports the work is held in contact with the work by means of the weighted lever *B*, fulcrumed in the frame.

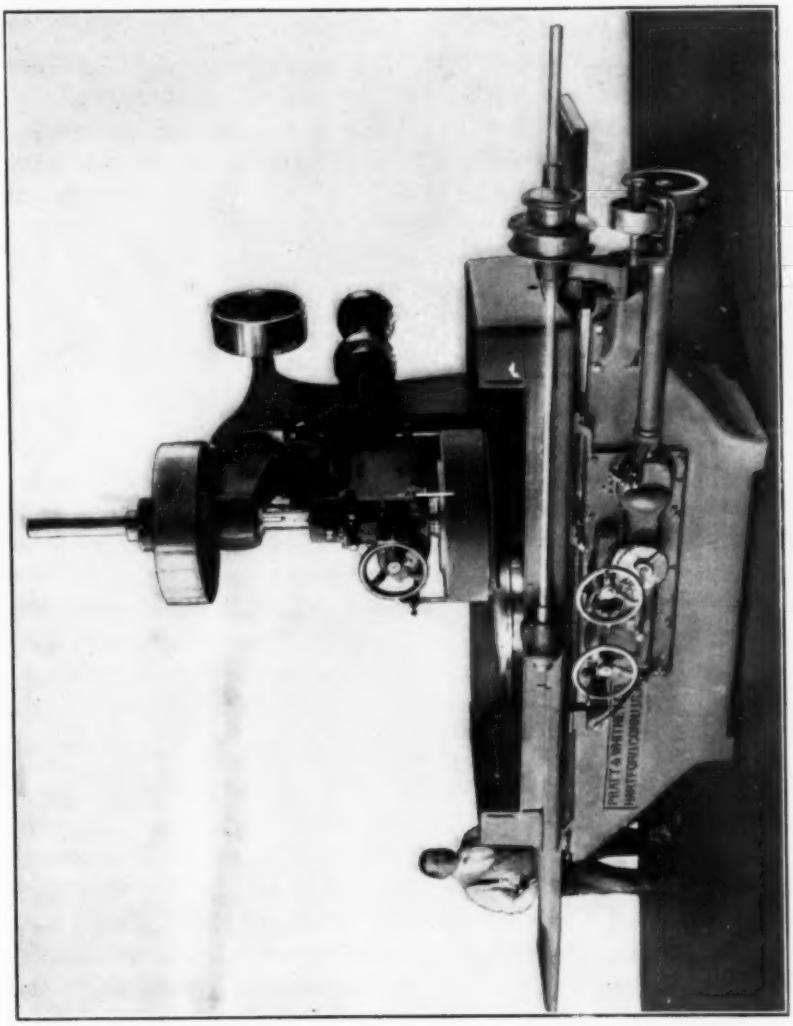

FIG. 5 SURFACE GRINDER, 25 IN. BY 60 IN., 30-IN. WHEEL; DRIVEN BY A 40-H.P. MOTOR

against the adjusting screw *D* at point C and causes the arm to slide in an upward direction on pin *E*. As lever *B* is depressed a roller *F* travels downward into the V-shaped space formed by the upper surface of lever *B* and the lower surface of the casting *G*, this roller preventing any upward movement of the lever and consequently any movement of the back rest away from the work.

15 As said before, surface grinders have usually been made with the wheel grinding on its periphery and in some instances it may be necessary to continue to do work on this principle, as grooves and irregular shapes sometimes have to be ground and the thinness of the wheel makes it possible to get into narrow places; but when flat surfaces are wanted, the cup-shaped wheel has taken a foremost place in grinding. The wheel covers the whole width of the work at once and water is forced through the center of the spindle, centrifugal force throwing the water outward and compelling it to pass between the work and the wheel. It is astonishing with what rapidity work can be reduced to a flat surface under this process.

16 This method of grinding would never have been successful if it had not been for the advancement in wheel making. The wheel problem in connection with the machine has been most difficult. It has been found very essential to select the right kind of wheel for different classes of work and for different materials. For grinding steel, either hardened or soft, corundum wheels have proved the best and for grinding cast iron the carborundum wheel has proved the best. The different degrees of hardness must be taken into consideration when the width of the surfaces to be ground varies.

17 The makers have decided to place on the market a much larger machine of this type than they have made before, shown in Fig. 5. This machine has a table stroke of 6 ft., and can grind a piece 6 ft. long and about 25 in. wide. It can also grind circular rings and disc surfaces up to 30 in. in diameter. The wheel has a diameter of 30 in. and the whole machine is driven from a single belt by a 40-h.p. motor. As this machine has just recently been built, its capability is not fully known, but for work that has already been tried it shows very encouraging results. For such work as grinding guide bars, slide valves and link motions for locomotives, large stamping dies such as are used in electric works, facing automobile cylinders and automobile engine frames, I believe it will show its superiority over any other method by several hundred per cent. In one of the trials a surface of cast iron, 6 ft. long and 20 in. wide was reduced in thickness 0.01 in. in five minutes, leaving an excellent finish and an exact

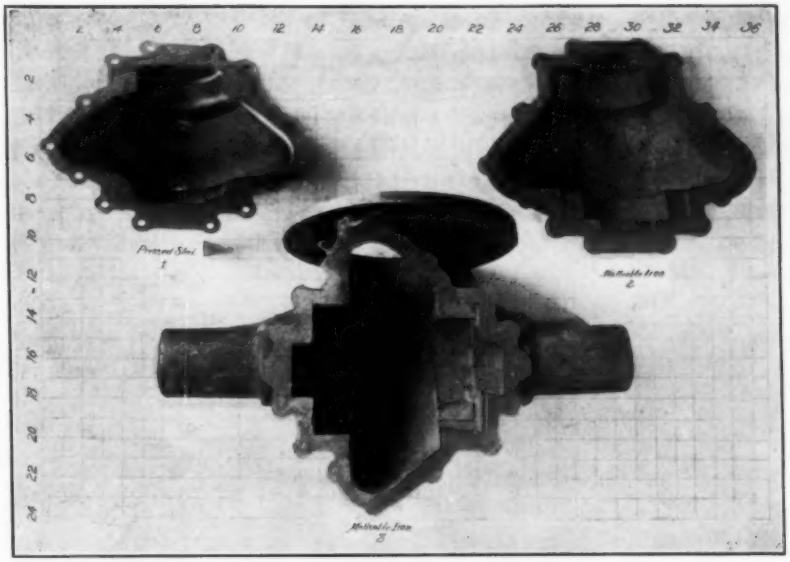

FIG. 6 EXAMPLES OF GRINDING: No. 1, PRESSED STEEL, 15 PER HOUR; No. 2, MALLEABLE IRON, 15 PER HOUR; No. 3, MALLEABLE IRON, 12 PER HOUR

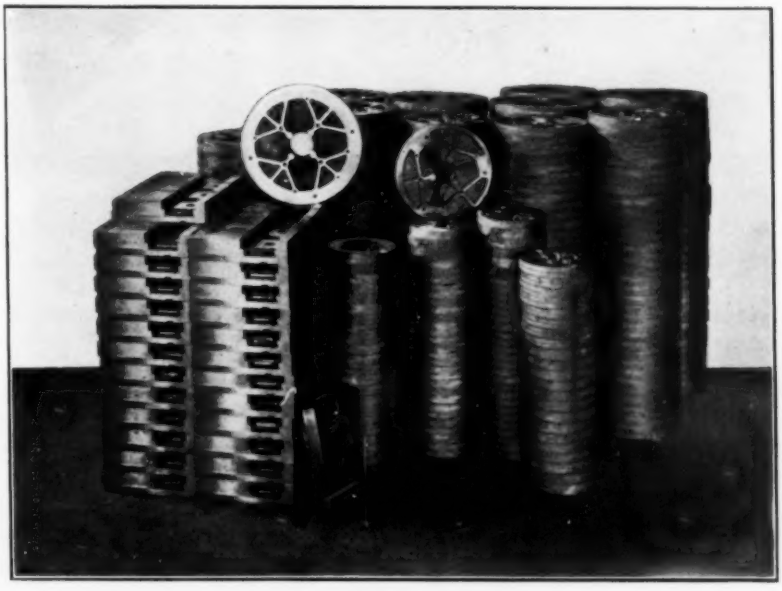

FIG. 7 EXAMPLES OF GRINDING: CHUCK PLATES, GROUND BOTH SIDES, 6-IN. 20 PER HOUR; 9-IN. 15 PER HOUR; 12-IN. 10 PER HOUR; VISES, GROUND ON TWO EDGES, TOP AND ONE CLEANED ONLY, 20 PER HOUR

flatness. In fact when tested no point in the surface showed out of true more than 0.0005 in. In grinding steel this type of surface grinder produces chips that look very much like metallic wool, which seems to indicate that when a cupped wheel passes over the work the chips are made by the outer edge of the wheel in the same manner as chips produced by the outer edge of an end milling cutter. If the chips were made underneath the broad contact surface of the wheel there would not be room for them to curl up in the small places which are left

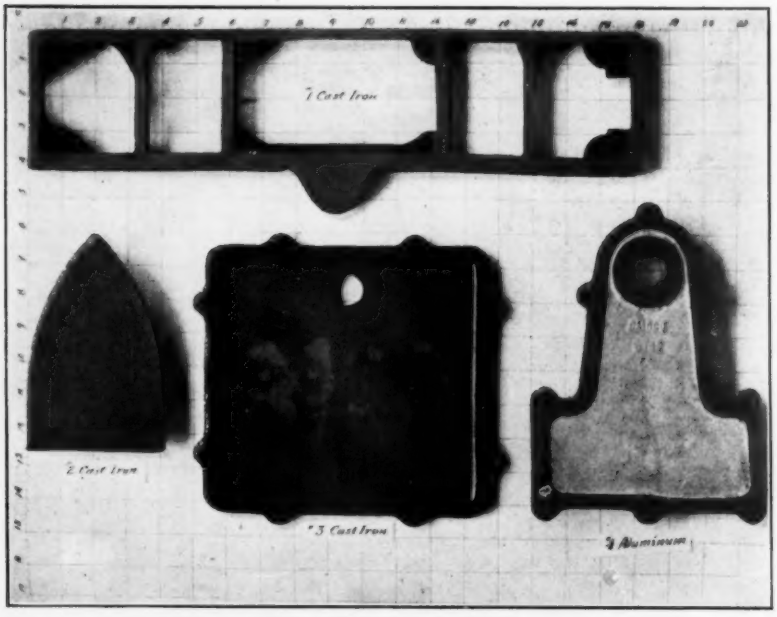

FIG. 8 EXAMPLES OF GRINDING: NO. 1, CAST IRON, 15 TO 20 PER HOUR; NO. 2, CAST IRON, 60 PER HOUR; NO. 3, CAST IRON, 25 PER HOUR; NO. 4, ALUMINUM, 30 PER HOUR

between each cutting particle of the grinding wheel. The large surface in contact with the work simply smooths the surface.

18 The table on these machines is provided with different feeds. It is difficult to make an exact rule as to what feeds to use for different materials, but the operator can determine this by running the machine a few minutes. The difficulty lies in the fact that wheels supposed to be made of the same specifications, vary considerably

and consequently the feed has to be regulated not only to suit the material being ground but also to suit the cutting ability of the wheel to be used. At the present time it is safe to say that grinding machinery is fully developed to the cutting capacity of the wheels and there will probably not be any essential changes until the grinding wheels have reached a higher development.

19 In Figs. 6 to 9 several photographs are shown of work which has been ground on vertical cupped-wheel machines. In some in-

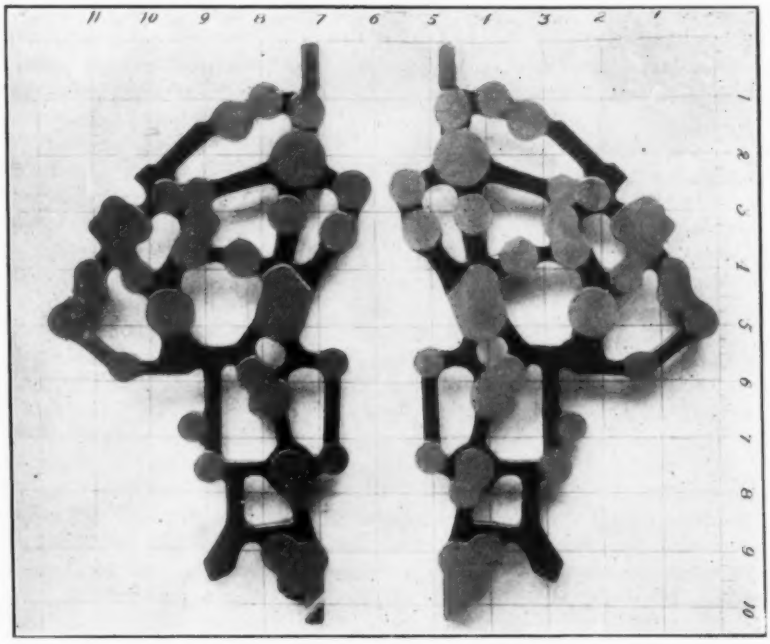

FIG. 9 EXAMPLE OF GRINDING: ADDING MACHINE FRAME, CAST IRON, 15 PER HOUR

stances such as in the production of small gun parts, like hammers and triggers, the work has been done from fifteen to twenty times faster than it can be milled and it has a smoother and more accurate surface. This is especially true where the surfaces are not too wide.

20 To give an idea of the capacity of a grinding machine having a cupped wheel for grinding flat surfaces, compared with a grinding machine having a wheel grinding on its periphery and working on the principle of a planer, it is worth while to note the following:

21 The traversing speed of the work or the work table can be assumed to be the same. If a piece is 6 in. long and 3 in. wide, the machine grinding on its periphery will take about 48 strokes to cover the surface, assuming $\frac{1}{16}$-in. feed for each stroke. The cupped-wheel machine will do the same amount of work with one stroke or in about $\frac{1}{24}$ the time. These proportions are essentially true on hardened steel or on any kind of work where a nice finish is required.

GENERAL NOTES

AMERICAN INSTITUTE OF MINING ENGINEERS

A meeting of the American Institute of Mining Engineers was held in the Canal Zone, Central America, November 1 to 8. About 125 members and guests of the Institute sailed from New York October 21 to attend the meeting. Stops were made en route at Havana, Cuba, for one day, and at Kingston, Jamaica, for two days.

At Havana the party was received at the Palace by President José Miguel Gomez. Each member was individually presented to the President, who expressed the pleasure it afforded him to meet such a distinguished gathering. The party was taken around the city and suburbs in automobiles and carriages and visited many historic places. Morro Castle, in particular, proved intensely interesting.

At Kingston, Jamaica, special trains and carriages were provided, to visit Constant Spring, Castleton Gardens, Bog Walk and Spanish Town.

The eight days in the Canal Zone were devoted to excursions to various points along the line of the Canal, to inspect engineering features of the undertaking.

Sessions for technical discussion were held on the steamer on the afternoons of Oct. 24, 27 and 28. The smooth sea and pleasant weather permitted these sessions to be held on deck. On October 24 and 27 the topic of Mine Fires was discussed with papers on the Summit Hill Mine-Fire, by W. S. Lathrop; Mine Fire at the Calumet and Hecla Mine, No. 8 Shaft, by S. D. Warriner, Mem. Am.Soc.M.E.; Fire in the Big Lick Stope, Lykens Valley and Williamstown Colliery, by R. V. Norris, Mem.Am.Soc.M.E.; Fire in the Monarch Mine, near Rock Springs, Wy., by S. A. Taylor; Fire in the Anaconda Mine, Butte, Mont., by David W. Brunton, and in the Leonard Mine, Butte, Mont., by Chas. W. Goodale; Mine-Fire in the Luke Fidler Colliery, Shamokin, Pa., by R. V. Norris, Mem.Am.Soc.M.E.; Four Fires at the Vulcan Mine, Vulcan, Mich., by William Kelly; Results of the Recent Explosion in the Esperanza Mine, Coahuila, Mex., by Edw. W. Parker; Fire in the Kimberley Mine, South Africa, by Gardner F. Williams; Gold-Mines of the Rand, by Hennen Jennings. At subsequent sessions papers were presented on the Production of Pig Iron by the Electric Furnace in Sweden, by Prof. Joseph W. Richards; Operations in the Canal Zone, by W. L. Saunders, Mem.Am.Soc.M.E.; The Social and Economic Conditions in Panama and the Canal Zone, by John M. Sherrerd, Mem. Am.Soc.M.E.; Coal-Mining Machinery, by E. W. Parker; Diamonds of the Rand, by Gardner F. Williams; Recent Water-Power Developments in Montana, and the Uses of Electric Power in Pumping, Compressing and Hoisting, by Chas. W. Goodale; The Manufacture of Electrical Machines for Mining Plants, by David B. Rushmore, Mem.Am.Soc.M.E.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

At the monthly meeting of the American Institute of Electrical Engineers on Friday evening, November 11, in the Engineering Societies Building, a paper on Interpoles and Synchronous Converters by B. G. Lamme and F. D. Newbury, both of the Westinghouse Electric and Manufacturing Company, Pittsburg, Pa., was presented for discussion.

AMERICAN MUSEUM OF SAFETY

The American Museum of Safety was opened on Monday evening, November 21, in the Engineering Societies Building, 29 West 39th Street, New York, under the supervision of the director, Dr. W. H. Tolman. This is designed to be the headquarters of a national movement directed to the conservation of human life, the sanitation of environments, and the prevention of accidents. The exhibits are in three sections: safety, sanitation and mutuality. The first classification includes safety devices and appliances relating to generation and transmission of power; fire and explosives; electricity, building trades, decorative arts; agriculture, mining, lumbering; foods and conserves; manufacture of machines, tools and apparatus; stone and earth; textiles, transportation by land and sea, and theatrical enterprises. The second covers water, ventilation, heating, lighting, dusts, sewage and its disposal, noise lessening, alcoholism and housing; while under the third are comprised service insurance, pensions, liability and compensation, thrift and saving funds. One of the conspicuous exhibits is a model of a modern house with fire-proof roofing, new water filters for household, factory, field and laboratory use, in which the filtering medium is a hollow cylinder made of infusorial earth.

This museum is similar to those in Europe, of which thirteen have already been established.

AMERICAN SOCIETY OF CIVIL ENGINEERS

The annual meeting of the American Society of Civil Engineers will be held in the society house, 220 W. 57th St., New York, on January 18 and 19, 1911.

NATIONAL MACHINE TOOL BUILDERS ASSOCIATION

The ninth annual meeting of the National Machine Tool Builders Association was held at the Hotel Astor, New York, October 25 and 26. The first day was entirely devoted to business and to meetings of the several section committees. At the morning session, October 26, the following papers were read: Who Should Pay the Expenses of a Representative from the Factory When Sent out at Request of the Dealer to Help Close the Deal. F. L. Eberhardt, Mem. Am.Soc.M.E., and C. H. Norton. The Use of Ball or Roller Bearings in Machine Tool Construction, Henry Hess, Mem.Am.Soc.M.E.; Advertising—Large Space in a Few Papers vs. Small Space in a Number of Papers, Thomas A. Moore; Concrete vs. Wood Flooring, J. N. Heald. The afternoon session

was opened with addresses on the Design and Construction of Machine Tools from the Users' Standpoint, C. K. Lassiter, Mem.Am.Soc.M.E., and John Riddell, Mem.Am.Soc.M.E. A striking commentary upon the work accomplished during the year is the increase in membership.

INTERNATIONAL CONGRESS OF REFRIGERATION

The second International Congress of Refrigeration was held at Vienna, Austria, October 5–16, 1910, and had a large attendance of Americans who were well represented in the papers presented. Among these were, The Relation of Micro-Organisms to Low Temperatures, Edwin F. Smith; New and Improved Methods in Manufacturing Ice, Van Rensselaer H. Greene; Investigations as to the Efficiency of Ammonia Compressors when Running under Dry and Wet System; Conditions of Acceptance, Various Tests of Materials and Parts entering into the Construction of Refrigerating Apparatus, Peter Neff; New Arrangements and Improvements in the Construction of Apparatus for Refrigeration, F. E. Mathews; Transportation of Perishable Freight in America, E. F. McPike. While the meeting place of the third congress had not yet been decided, an invitation to hold it in the United States has been extended to the organization by President Taft and was warmly seconded by the Americans present.

INTERNATIONAL CONGRESS OF MINING, METALLURGY AND PRACTICAL GEOLOGY

An International Congress devoted to Mining, Metallurgy and Geology was held at Dusseldorf, Germany, June 20 to 24, and was attended by about 1500 engineers, of whom, however, less than a dozen were from North America. The arrangements for the Congress were made by a committee representing the principal German iron and steel manufacturers in the lower Rhine district, of which Dusseldorf is a principal center, the chief responsibility being carried by Dr. Ing. H. C. Emil Schroedter, Secretary of the Verein Deutscher Eisenhuttenleute, the great German society of iron and steel metallurgists.

A long list of papers was prepared for the Congress dealing with the latest practice in iron and steel metallurgy, mining and practical geology and the machinery used in mining and in steel production. In order to cope with this varied field, the Congress met in four different sections for the presentation and discussion of the papers in these several lines of work. The technical sessions of the Congress took place on Monday, June 20 and Tuesday, June 21. While the bulk of the papers read were by German engineers, there were also important papers contributed from the United States and Canada and from England, France and other European countries outside of Germany. The complete papers and discussions at the Congress are to be published in a bound volume at an early day.

The remainder of the time was devoted to excursions to iron and steel works, mines, etc., in the Dusseldorf district and to enjoyment of the lavish entertainment provided for the visitors by the city of Dusseldorf. Over 30 of the

important iron and steel works, machine shops and mines in the vicinity of Dusseldorf were opened to inspection, and the delegates to the Congress, divided into parties of convenient size, spent Wednesday and Thursday in visits to these different establishments.

On Tuesday evening the visitors were entertained at a dinner given by the city of Dusseldorf in the Tonhalle, or Municipal Concert Hall. On Wednesday evening they were taken on a steamboat excursion on the Rhine concluding with a general illumination of the city's waterfront and display of fireworks, with Count Zeppelin of dirigible balloon fame as the guest of honor. On Thursday the entire party assembled at Essen, where the concluding session was held in the hall of the Rhenish-Westphalia coal syndicate. Addresses were made by delegates from each country participating in the Congress and it was stated that a permanent organization had been formed which will arrange for future sessions of the Congress, the next one to be held in London in 1915 by invitation of the delegates from Great Britain. After adjournment the delegates were entertained by the city of Essen, at a dinner and entertainment in the municipal concert hall and garden. On Friday a large number of the delegates were taken on an excursion to Brussels, where the Exposition was visited.

The Society was represented at the Congress by Vice-President Charles Whiting Baker of New York, Editor of Engineering News.

NATIONAL SOCIETY FOR THE PROMOTION OF INDUSTRIAL EDUCATION

The fourth annual convention of the National Society for the Promotion of Industrial Education was held in Boston, November 17–19, 1910. Thursday was occupied with two sessions, one in the morning on the subjects, Demands and Opportunities for Girls in Trades and Stores, with addresses by Dr. Susan M. Kingsbury, D. S. Edwards, Mrs. Lucinda W. Prince and others; and one in the afternoon on the Training of Teachers for Girls' Trade Schools, with Mrs. Mary S. Woolman, Sarah Louise Arnold, Florence M. Marshall, as the speakers. On Thursday evening a public banquet was given in the Hotel Somerset and a welcome extended by the Lieutenant Governor of Massachusetts and by the Mayor of Boston. Speeches were also made by Frederick A. Delano, Frederick P. Fish, Chas. H. Winslow and Prof. Chas. R. Richards, Mem.Am.Soc.M.E., and President of the National Society for the Promotion of Industrial Education.

At the sessions of Friday, Apprenticeship and Corporation Schools were considered in the morning, Magnus W. Alexander, Mem.Am.Soc.M.E., acting as chairman, with addresses by Tracy Lyon, Mem.Am.Soc.M.E., F.W. Thomas, Samuel F. Hubbard, George G. Cotton, Mem.Am.Soc.M.E., and G. M. Basford, Mem.Am.Soc.M.E. In the afternoon addresses on the subject of Part Time and Evening Schools were made by W. B. Hunter, Adelbert L. Safford, Frank B. Dyer, Stratton D. Brooks and C. A. Prosser. Dr. George Kezschensteiner, Superintendent of Schools in Munich, delivered a lecture on Friday evening on Continuation Schools of Germany. At the concluding professional session on Saturday, the Social Meaning of Industrial Education was considered, with T. N. Carver, Chas. H. Winslow and others as the speakers.

The officers for the ensuing year, elected at the annual business meeting, are President, Chas. R. Richards, Mem.Am.Soc.M.E., Director of Cooper Union; Vice-President, J. W. Lieb, Jr., Mem.Am.Soc.M.E., New York Edison Co.; Treasurer, Frederic B. Pratt, Pratt Institute, Brooklyn; Secretary, Edward H. Reisner, Columbia University.

NEW YORK ELECTRICAL SOCEITY

The New York Electrical Society is signalizing the 40th year of its existence by a series of lectures on electricity and applied science. The program comprises addresses on Animated Photography in Natural Colors, by Gilbert H. Aymar; The Effect of the Telephone on Modern Industrial and Social Life, by Herbert N. Casson; The Catskill Water Supply, by Hon. Chas. N. Chadwick; Electricity at the Panama Canal, by David B. Rushmore, Mem.Am.Soc.M.E; Hydro-Electric Development in Mexico, by F. O. Blackwell; The Rapid Transit Problem of New York City, by H. St. Clair Putnam; Wave Motion by Electricity and Other Energy, by Dr. Chas. P. Steinmetz,Mem.Am.Soc.M.E.; The Physics of Light Sources, by Dr. Edward P. Hyde; The Relation of the Modern Incandescent Lamp to the Central Station, by S. E. Doane. All of these lectures, with the exception of that by Mr. Blackwell which will be delivered in the Hispanic Society Building, will be given in the Engineering Societies Building, and a card of invitation can be secured on application by any member of The American Society of Mechanical Engineers from the Secretary, Mr. George H. Guy.

SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS

The eighteenth general meeting of the Society of Naval Architects and Marine Engineers was held in the Engineering Societies Building, New York, November 17 and 18. Among the papers read were: Notes on the Armaments of Battle Ships, Sir William White; The Evolution of Screw Propulsion in the United States, Part 2, Charles H. Cramp; The History and Economic Value of Canals with Special Reference to the Cape Cod Canal, Jacob W. Miller; Coaling War Ships; Notes of Progress, Spencer Miller; Floating Dry Docks in the United States; Relative Value of Wood and Steel for their Construction, William T. Donnelly; Our Constitutional Shipping Policy and the Compact for its Establishment, William W. Bates; An Analysis of Tests of Watertight Bulkheads, with Practical Rules and Tables for their Construction, William Hovgaard; Comparative Results in Steam and Coal Consumption with Turbines, Reciprocating Engines and a Combination of the Two, on the Steam Yacht Vanadis, Clinton H. Grane; The Gyroscope for Marine Purposes, Elmer A. Sperry; New Propelling Machinery of the S. S. Creole, John F. Metten; Some Suggestions for Reducing Loss by Fire on Shipboard, Samuel D. McComb; Two Marine Installations of Producer Gas Power, Charles B. Page.

PERSONALS

Alfred R. Bench, formerly connected with the W. H. Zimmerman Co., Chicago, Ill., has become associated with the Taylor Iron & Steel Co., High Bridge, N. J.

Joseph Breslove has entered the employ of the Nivison-Weiskopf Co. Until recently he was associated with the Westinghouse Machine Co., East Pittsburg, Pa.

Edwin H. Brown has formed a partnership with Edwin H. Hewitt under the firm name of Hewitt & Brown, Architects and Engineers, with offices in Minneapolis, Minn. Mr. Brown was until recently identified with the Cadwell & Brown Co., Minneapolis, Minn.

Thurlow E. Coon and John DeVisser have formed a partnership, under the firm name of Coon-DeVisser Co., with offices in Detroit, Mich. They will conduct a general power plant business.

William T. English, formerly president of the English & Flett Co., Inc. Boston, Mass., is now president of the Walworth-English-Flett Co., of the same city, a consolidation of the company with the Walworth Construction & Supply Co.

A. E. Greene has resigned his position as chief engineer of the New Departure Manufacturing Co., Bristol, Conn., and has opened an office in Hartford, Conn.

Charles A. Howard has become identified with Gunn, Richards & Co., New York as mechanical engineer. He was formerly manager of the turbine department of E. W. Bliss Co., Brooklyn, N. Y.

R. M. Hvid has accepted a position with the Advance Thresher Co., Battle Creek, Mich., as engineer in charge of construction.

L. L. Johnson has resigned his position as gas engineer of the electrical department of the Southern Pacific Co., San Francisco, Cal., to take up consulting engineering relative to gas power and fuel plants, with office in Indianapolis, Ind.

W. A. Kennedy, formerly instructor of mechanical drawing, Brown University, Providence, R. I., has become testing engineer of the General Fire Extinguisher Co., of the same city.

Gompei Kuwada has become associated with the Osaka Gas Co., Osaka, Japan. He was formerly superintendent of machine shops, Kawasaki Dock Yard Co., Kobe, Japan.

Kenneth B. Millett has entered the employ of the Newburgh Ice Machine & Engine Co., Newburgh, N. Y. Until recently, Mr. Millett was factory superintendent of the Protal Co., Bridgeport, Conn.

J. E. Muhlfeld, formerly general superintendent of motive power of the B. & O. R. R., Baltimore, Md., has been appointed vice-president and general manager of the Kansas City Southern Railway, Kansas City, Mo.

C. D. Pettis, formerly associated with the Hewitt Manufacturing Co., Chicago, Ill., has accepted a position with the American Brake Shoe & Foundry Co. of the same city.

Hollis P. Porter, recently president and manager of the Schlafli & Porter Co., Houston, Tex., has accepted a position with the Cerro de Pasco Mining Co., Peru, S. A., as chief engineer of power.

A. J. Purinton has become associated with the St. Joseph Railway, Light, Heat & Power Co., St. Joseph, Mo., in the capacity of general superintendent. He was formerly manager for receiver, Toldeo & Chicago Interurban Railway Co., Kendallville, Ind.

Paul S. Rattle has recently taken charge of the pump and compressor department of the Mine & Smelter Supply Co., Denver, Colo. Mr. Rattle was formerly associated with the Hicks Locomotive & Car Works of the same city.

David H. Ray was appointed chief engineer of the Bureau of Buildings of the Borough of Manhattan. He was formerly associated with the faculty of the College of the City of New York.

William A. Richards has been placed in charge of the machine shops of the University High School, University of Chicago, Chicago, Ill., in addition to the forge and foundry which he has had for the last two years.

Wilbur N. Sar Vant has accepted the position of assistant chief engineer of the Standard Turpentine Co. of Florida, Jacksonville, Fla.

Ernest B. Sellew, formerly chief draftsman of Potter & Johnston Co., Pawtucket, R. I., has been appointed president and manager of the Sellew Machine Tool Co. of the same city.

Charles P. Smith formerly associated with the General Electric Co., Lynn, Mass., has become identified with the Lower Pacific Mills, Lawrence, Mass.

William S. Twining has become identified with Ford, Bacon & Davis, New York. He was until recently chief engineer of the Philadelphia Rapid Transit Co., Philadelphia, Pa.

James A. White, formerly connected with the General Electric Co., Lynn, Mass., has accepted a position with the Worcester Pressed Steel Co., Worcester, Mass.

Alan G. Williams has been appointed general foreman of the Buffalo Shops of the Pennsylvania R. R. Co. He was formerly night enginehouse foreman of the Co. at Oil City, Pa.

ACCESSIONS TO THE LIBRARY

This list includes only accessions to the library of this Society, included in the Engineering Library. Lists of accessions to the libraries of the A. I. E. E. and A. I. M. E. can be secured on request from Calvin W. Rice, Secretary, Am. Soc. M. E.

AMERICAN STREET AND INTERURBAN RAILWAY ACCOUNTANTS ASSOCIATION. *1910.* Papers read at Convention, 1910. Gift of American Street and Interurban Railway Association.

AMERICAN STREET AND INTERURBAN RAILWAY TRANSPORTATION AND TRAFFIC ASSOCIATION. Papers read at Convention, 1910. *1910.* Gift of American Street and Interurban Railway Association.

ASOCIACION DE INGENIEROS Y ARQUITECTOS DEL URUGUAY. Revista. Ano. 11–1908. *Montevideo, 1908.*

CAMBRIDGE (MASS.) WATER BOARD. Annual Report 1909–1910. *Cambridge, 1910.*

DECIMAL ASSOCIATION. Report of Debate on the Metric System in the House of Representatives of the Commonwealth of Australia on August 4, 1910. *London.*

FRANKLIN INSTITUTE. Index to the Journal. 1826–1885. *Philadelphia, 1890.* Gift of H. R. Towne.

INDICATOR HANDBOOK. Ed. 4. By C. N. Pickworth, *New York, 1910.* Gift of the author.

MEMORIALS OF THE LINEAGE, EARLY LIFE, EDUCATION AND DEVELOPMENT OF THE GENIUS OF JAMES WATT. By George Williamson. 1856. Gift of George Tangye, Esquire.

METHODS OF PROTECTING EMBANKMENTS AGAINST CURRENTS AND RESTORING THEM WHEN WASHED OUT. Report of committee.

MODERN EQUIPMENT OF COAL MINES. By W. C. Mountain. Paper read before the Indian Section of the Institution of Mechanical Engineers, January 26, 1910.

MONOGRAPHIE SUR L'ETAT ACTUEL DE L'INDUSTRIE DU FROID EN FRANCE. Congrès de Vienne, October 1910. *Paris, 1910.* Gift of J. C. Bertsch.

NEW ORLEANS. Sewerage and Water Board. 21st Semi-Annual Report. 1910. *1910.* Gift of the board.

WORLD CORPORATION. By K. C. Gillette. *Boston, New England News Co., 1910.* Gift of the author.

EXCHANGES

AMERICAN STREET AND INTERURBAN RAILWAY ENGINEERING ASSOCIATION. Papers read at Convention, 1910.

ENGINEERS SOCIETY OF WESTERN PENNSYLVANIA. Proceedings. vol. 25. *Pittsburgh, 1909.*

ENGINEERS SOCIETY OF WESTERN PENNSYLVANIA. Charter, By-Laws, List of Members, September 15, 1910. *Pittsburgh, 1910.*

INSTITUTION OF CIVIL ENGINEERS OF IRELAND. Transactions. vol. 36. *Dublin, 1910.*

THE TRANSIT. vol. 14, 15. *Iowa City, 1909, 1910.*

GIFT OF MR. J. C. BERTSCH

APERÇU SOMMAIRE DE L'ETAT ACTUEL DE L'APPLICATION DU FROID AU COMMERCE ET À L'INDUSTRIE EN RUSSIE. *St. Petersburg, 1910.*

BERICHTE AN DEN ZEITEN INTERNATIONALEN KALTEKONGRESS IN WIEN 1910. *Kopenhagen, 1910.*

EIS UND KALTE INDUSTRIE vol. 12, no. 10. *October 1910.*

CONGRÈS INTERNATIONAL DES INDUSTRIES FRIGORIFIQUES, VIENNE, 6–11. Octobre 1910. Notice sur l'industrie frigorifique des viandes dans la Republique Argentine. *Buenos Ayres, 1910.*

L'INDUSTRIE FRIGORIFIQUE. April 1910. *Paris, 1910.*

INTERNATIONALEN KÄLTEKONGRESSES. *Wien, 1910.* Bulletin no. 5–7, 1910.

KÄLTE INDUSTRIE, vol. 7. number 10. October 1910. *Hamburg, 1910.*

KÜHLANLAGEN DER K. K. REICHSHAUPT AND RESIDENZSTADT WIEN.

TRANSPORTS DES DENREES PERISSABLES SUR LE RESEAU FERRE DE L'EMPIRE RUSSE. Par D. de Golovnine. *Moscow, 1910.*

ÜBER DIE OEKONOMIK UND STATISTIK DER WARMEWIRTSCHAFT BEI DER KUNSTLICHEN KÄLTEERZEUGUNG. *St. Petersburg, 1910.*

ZEITSCHRIFT FÜR EIS UND KÄLTE INDUSTRIE vol. 3, no. 4, October 1910. *Vienna, 1910.*

ZEITSCHRIFT FÜR DIE GESAMMTE KÄLTE INDUSTRIE, vol. 17, number 10. *Munich, 1910.*

INTERNATIONAL REFRIGERATION CONGRESS (2D), VIENNA 1910

ABATTOIRS AND MARKETS OF PRAGUE. By Em. Stehlik.

ALIMENTATION DES NATIONS. By A. de Wendrich.

ANWENDUNG DER KÄLTE BEI DER ERZEUGUNG VON AZOFARBSTOFFEN. By Daniel Rittermann.

ANWENDUNG DER KÄLTE BEI DER BEHANDLUNG VON HAUTKRANKHEITEN. By Eduard Schiff.

DIE ANWENDUNG DER KÄLTE IN DER CHIRURGIE. By Hans Lorenz.

DIE ANWENDUNG DER KÄLTE IN DER MARGARINE-FABRIKATION. By F. Barth.

ANWENDUNG KÜNSTLICHER KÄLTE IN HÜTTENWERKEN. By R. C. A. Banfield.

ANWENDUNG UND EINRICHTUNG VON OZONAPPARATEN IN KÜHLRAÜMEN. By Alois Schwarz.

APPLICATION OF ARTIFICIAL COLD IN THE MANUFACTURE OF PARRAFFIN IN AUSTRIA-HUNGARY. By Philipp Porges.

APPLICATION OF ARTIFICIAL COLD IN PLANT CULTIVATION. By P. de Vries.

APPLICATION OF COLD IN OIL-GAS PRODUCER PLANTS. By J. Reidrer.

APPLICATION OF LOW TEMPERATURES TO THE CURING AND STORAGE OF CHEDDAR CHEESE. By. S. M. Babcock.

Application of Refrigeration to the Glue and Gelatine Industry. By Paul Cavalier.

Application of Refrigeration to the Retarding of Plants and the Preservation of Flowers. By L. C. Corbett.

Application of Refrigeration to the Raw Materials of the Perfumery Industry. By Paul Jeancard.

Arrangement and Management of Open-Air Artificial Ice Rinks. By E. Engelmann.

Artificial Production of Low Temperature in the Biological Experimenting Establishment. By H. Przibram.

Bedeutung und Anwendung niedriger Temperaturen in der Textilindustrie. By F. Erban.

Beer Transport on Railways. By Alois Holitsch.

Changes in the Physical and Morphological Conditions of Food Stuffs (meat fish and milk) by Cold. By Dr. Butzler.

Cold Technics in Connection with the Paraffin Industry in Holland and the Dutch Colonies. By E. S. Kerkhoven.

Cold Without Fuel, and its Consequences. By Ch. Tellier.

Conditions of Acceptance, Various Tests (resistance, stanchness, etc.) of the Materials and Parts Entering into the Construction of Refrigerating Apparatus. By Peter Neff.

Effect of Cold Storage upon the Bacteriological and Chemical Changes in Milk and Butter. By Chas. E. Marshall.

Effect of Low Temperatures on the Life Process of Fruits and on the Rate of Fermentation of Cider. By H. C. Gore.

Einfuhr und Ausfuhr von Fleisch in den Verschiedenen Ländern und Beantwortung der Frage: ist für die Niederlande die Einfuhr von gefrorenem und gekühltem Fleisch aus dem Auslande Wünschenswert. By F. B. Lohnis and D. A. de Jong.

Elektrischen Fernthermometer. By J. Rautenkrantz.

Experiments on Dry and Wet Compressor Procedure of Condensing Cold Steam Machines. By Adolph Tegetmayer.

La Fabrication de la Glace. By Mr. Sandras.

Fabrikationsprozesse, welche zur Gewinnung von Paraffin unter verwendung von Künstlicher Kälte dienen.

Fleischfrage und Kälte-industrie. By Eugen Vamos.

Handling Ice at Ice Plants and Car Icing Stations. By H. B. Wood.

Importance of Refrigeration for Foods with Special Consideration of Milk. By Hans Messner.

Improved Method of Packing Gutted Fish for Transport and Keeping it Fresh and Sweet for a Long Time. By A. Sölling.

Influence and Application of Cold in Mercerising. By A. Kirchacker.

Installations Frigorifiques de la Ville de Prague. By Louis Cizek.

Instruction in Cold Technics in Holland. By M. de Haas.

International Refrigeration Congress, Vienna, 1910. Programme of the Commission on Transportation. By R. Bloch.

Investigations as to the Efficiency of Ammonia Compressors when Running under Dry and Wet Conditions. By T. Shipley.

Kontrolle der Kühlanlagen. By E. Jalowetz.

KÜHLANLAGEN ALS AKKUMULATOREN FÜR DIE ARMEEVERSORGUNG IM FELDE. By H. Heiss.

MANUFACTURE OF CRYSTAL ICE FROM EXHAUST STEAM AND THE PRACTICAL RESULTS OBTAINED BY THIS PROCESS. By R. C. A. Banfield.

NEW AND IMPROVED ARRANGEMENTS IN THE INSTALLATION AND OPERATION OF ICE FACTORIES. By Van R. H. Green.

NEW ARRANGEMENTS AND IMPROVEMENTS IN THE CONSTRUCTION OF APPARATUS FOR REFRIGERATION, RESULTS OF EXPERIMENTS THEREON. By F. E. Matthews.

DIE ORGANIZATION DER KÄLTE-VEREINE. By Alois Schwarz.

POSSIBILITY OF EMPLOYING TURBO-BLOWERS AS COOLING MACHINE CONDENSERS. By Hans Lorenz.

PRECOOLING OF FRUIT IN THE UNITED STATES. By S. J. Dennis.

REFRIGERATING PLANTS ON SHIPS. By H. Wagner.

REFRIGERATION AND VENTILATION OF INHABITED PLACES. By H. Torrance, Jr.

RELATION OF MICRO-ORGANISMS TO LOW TEMPERATURES. By E. F. Smith.

SHAFT SINKING BY FREEZING PROCESS. By Franz Drobniak.

SUPERHEATED VAPORS EMPLOYED IN REFRIGERATION. By J. E. Siebel.

STATISTICS OF REFRIGERATED TRANSPORTATION. By M. A. de Wendrich.

TRANSPORTATION OF PERISHABLE FREIGHT IN AMERICA. By E. F. McPike.

UNTERSUCHUNGEN ÜBER DIE KONSERVIERUNG VON PFERDEFLEISCH MITTELS KÄLTE UND DEREN VERWENDUNG ZU NAHRUNGSZWECKEN.

USE OF COLD IN THE PHARMACEUTIC PRODUCTS INDUSTRY. By E. Tassilly.

USE OF COLD FOR DESTROYING TOBACCO WORM. By G. Poock.

VERSICHERUNGSWESEN IN SEINEM ZUSAMMENHANGE MIT DER KÄLTEINDUSTRIE. By Emil Regen.

WARMTH CONDUCTION OF PULVEROUS BODIES AND A NEW SYSTEM OF WARMTH ISOLATION BASED THEREON. By M. V. Smoluchowski.

WAS SOLL MAN UNTER DEM OEKONOMISCHEN WIRKUNGSGRAD EINER KÄLTEMASCHINE VERSTEHEN. By A By A. Satkewitsch. *Berlin, 1910.*

WELCHE ANSPRUCHE SIND AN EINEN GUTEN KÜHLWAGEN ZU STELLEN.

ZWECKMASSIGE KÜHLANLAGEN AN MODERN EINGERICHTETEN SCHLACHTHOFEN. By Mr. Dohmann.

TRADE CATALOGUES

BRISTOL CO., *Waterbury, Conn.* Bull. No. 126, Class II recording thermometers, 314; Bull. No. 128, Round form, class II, 8-inch, recording thermometers, 3 pp.; Bull. No. 129, Thermometer, Thermostats, classes I, II and III, 7 pp.; Bull. No. 135, Recording shunt ammeters for all ranges of direct current, 7 pp.; Bull. No. 141, Round form recording pressure gages, 11 pp.; Bull. 145, class II indicating thermometers, 1 pp.; Bull. No. 146, Long-distance recording tachometers, 1 p.; Bull. No. 147, Bristol-Durand radii averaging instrument, 3 pp.

BUFF & BUFF MFG. CO., *Boston, Mass.* High grade engineering, surveying, and mining instruments, 117 pp.

BUILDERS IRON FOUNDRY, *Providence, R. I.* Venturi hot water meter for boiler feed, etc., 16 pp.

CALDWELL ECONOMY CO., *New York.* Westover multiple record CO_2 recorder, 4 pp.

CHAMPION RIVET CO., *Cleveland, O.* Boiler, ship, and structural rivets, 83 pp.

C. & G. COOPER CO., *Mount Vernon, O.* Seventy-five years of engine building; a history of the Cooper works and their products, 50 pp.

HESS-BRIGHT MFG. CO., *Phila., Pa.* Ball bearings and their correct use, 5 pp.

INDUSTRIAL INSTRUMENT CO., *Foxboro, Mass.* Foxboro Recorder vol. 4, No. 2, 14 pp.

H. W. JOHNS-MANVILLE CO., *Cleveland, O.* J.-M. Packing Expert, October 1910, 4 pp.; J.-M. Roofing Salesman, November 1910, 8 pp.

J. GEO. LEYNER ENGRG., WORKS CO., *Littleton, Colo.* Bull. No. 1024, Leyner stoppers, dry pattern for solid steel, 10 pp.

NATIONAL ELECTRIC LAMP ASSOC., *Cleveland, O.* Bull. No. 13, Mazda multiple lamps, 19 pp.; Bull. No. 14, Hylo-economical, turn-down electric lamps, 11 pp.

NORTH WESTERN EXPANDED METAL CO., *Chicago, Ill.* Designing data II for reinforced concrete, 46 pp.

OSGOOD SCALE CO., *Birmingham, N. Y.* Standard scales of all styles, 94 pp.

STANDARD UNDERGROUND CABLE CO., *Pittsburg, Pa.* Handbook of price lists, 228 pp.; Leaflets on wires and cables, 26 pp.; Varnished cloth insulated wire and cable, 12 pp.; Open air cable terminals, 8 pp.; Colonial copper clad wire, 32 pp.; Joints and jointing material, 20 pp.

TERRY STEAM TURBINE CO., *Hartford, Conn.* Bull. No. 7, Three bearing type gas blower set, 7 pp.

TEXAS CO., *Houston, Texas.* What is asphalt, 8 pp.; Texaco paving filler, 16 pp.; Texaco paving cement, 15 pp.; Texaco, the road builder, 18 pp.

UNDERFEED STOKER CO. OF AMERICA, *Chicago, Ill.* Publicity Magazine, November, 1910, 15 pp.

UNITED ENGINEERING SOCIETY

ENGINEERING NEWS. Index 1905–1909. *New York, 1910.*

KELLEY'S DIRECTORY OF ENGINEERS AND IRON AND METAL TRADES. 1909. *London, 1909.*

MODERN ACHIEVEMENT. Vol. 1–10. *New York.* Gift of J. A. Coles.

MOODY'S MANUAL OF RAILROADS AND CORPORATION SECURITIES. 1910. *New York, 1910.*

NEW CENTURY REFERENCE LIBRARY. Vol. 1–8. *New York, 1910.* Gift of J. A. Coles.

SCIENCE-HISTORY OF THE UNIVERSE. Vol. 1–10. *New York, 1910.* Gift of J. A. Coles.

EMPLOYMENT BULLETIN

The Society has always considered it a special obligation and pleasant duty to be the medium of securing better positions for its members. The Secretary gives this his personal attention and is most anxious to receive requests both for positions and for men available. Notices are not repeated except upon special request. Copy for notices in this Bulletin should be received before the 12th of the month. The list of men available is made up of members of the Society and these are on file, with the names of other good men not members of the Society, who are capable of filling responsible positions. Information will be sent upon application.

POSITIONS AVAILABLE

057 Instructor in kinematics wanted in an eastern college, to give text book, lecture and drawing room course in the subject. In applying state technical education and practical experience, references and salary expected.

058 Large manufacturing company in Pennsylvania, organizing a department of engineering sales, offers opportunities in this department to three or four bright, hustling, young engineers. Accepted applicants will be required to spend a few months in drawing room and shops prior to taking up work as traveling sales engineers. Salary to commence, $800 to $1000 a year.

059 Member, engaged in inspection, investigations reports, etc., desires to communicate with one who would buy an interest in present business to which another specialty might be added.

060 Competent engineer, good draftsman and designer with experience in steam and power pump construction. Location Michigan.

MEN AVAILABLE

143 Technical graduate in mechanical engineering and manual training school,—Junior member, married,—four years' experience, engaged in special work in large industrial plant, nature to be of benefit in almost any line. Desires change of position, permanency sought.

144 Stevens graduate, 17 years experience, design, construction and management of manufacturing plants, patents, cost system, purchasing; specially interested in economics, organization and reduction of costs, from boiler room to finished product. Desires position in executive capacity, with a new business or one needing reorganizing, prefer New York City. If satisfactory would invest in the undertaking.

145 Mechanical engineer, graduate Stevens Institute of Technology; executive ability, experience in industrial engineering and factory management, design, construction and supervision of complete power plant equipment; successful commercial engineer; at present holding a managerial position, wishes to represent or become associated with a firm in New York preferred where initiative and business ability coupled with technical education will lead to executive responsibility. Best of references.

146 Member desires position as general superintendent, representative, or consulting engineer in Boston or other New England manufacturing concern, devoting all or part of time.

147 Associate Member, American, married, successful experience as machinist, tool and model maker, foreman and works manager, broad, practical experience as manufacturer of instruments of precision, tools and jigs for the rapid out-put of parts in manufacturing; over six years varied experience, building, starting new factories and selling in the Orient; open for a position in an executive capacity or superintendent. Location no object. Would travel.

148 Young engineer, Junior member, Stevens graduate, married, experience in operation end of manufacturing concerns, erection, maintenance and repairs of steel mills, decorticating, saw mill, textile, coal handling, and power plant machinery. Desires position in executive capacity with concern manufacturing machinery in these or associated lines. Location East or Middle West.

149 Sales engineer, would consider position where knowledge of machinery and mill supply trade of the United States and Canada is essential; seven years varied engineering experience; six years in selling end. Experience in correspondence and design of selling contracts.

150 Veteran engineer and sales office manager for over twenty years desires position where acquaintanceship and standing among fellow members and thorough understanding of steam specialty business will be of value in improving or putting product on market. Practical mechanic.

151 Superintendent and works manager, thoroughly capable in every department, desires change. Technical and practical education, long experience in handling men, shop accounting, special engineering, foundry and shop management. At present in charge of large plant manufacturing transmission machinery and large jobbing line.

152 New York member, twenty-five years practical experience in steam engineering, designing, contracting for installing and operating steam power and heating plants. Technical education. Desires position as engineer in charge or would associate with capitalist or company to contract for above work.

153 Graduate civil engineer with general railroad field work, construction and maintenance of way; three years in engineering department of large electrical company, two in full charge of structural department; held positions as chief draftsman in charge of all classes of work, handling complete designs of power stations, etc., structural engineer, consulting engineer or superintendent of construction.

CHANGES IN MEMBERSHIP

CHANGES OF ADDRESS

ABRAHAMS, M. Landa (Junior, 1910), 2106 Arch St., Philadelphia, Pa.

ALLEN, John Robins (1984; 1903), Prof. Mech. Engrg., 221 New Engrg. Bldg., Ann Arbor, Mich.

ANDERSON, Emanuel (Associate, 1907), 5301 Kenmore Ave., Chicago, Ill.

ARMSTEAD, Frank C. (1906), Engr. Stoker Dept., Westinghouse Mch. Co., 165 Broadway, New York, and *for mail*, 1085 E. 17th St., Brooklyn, N. Y.

BANFIELD, Frederic E., Jr. (Junior, 1909), Mech. Engr., Saco & Petee Mch. Co., and *for mail* 17 Woodward St., Newton Highlands, Mass.

BASINGER, James G. (1907), Civ. Engr., 52 Broadway, New York, and 181 Bowne Ave., Flushing, L. I., N. Y.

BEDELL, Edgar Harrington (Junior, 1910), 216 Mt. Prospect Ave., Newark, N. J.

BENCH, Alfred Rittscher (Junior, 1907), Taylor Iron & Steel Co., High Bridge, N. J.

BEVIN, Sydney (Junior, 1909), 150 W. 76th St., New York, N. Y.

BORDE, George U. (1909), Cons. Engr., 820–822 Hibernia Bldg., New Orleans La.

BRAINE Bancroft G. (1896; 1905), Engr., Rail Joint Co., 185 Madison Ave., New York, and 67 First Pl., Brooklyn, N. Y.

BRAUN, Carl F. (Junior, 1907), Pres., Braun, Williams & Russell, Inc., 503 Market St., S. E., San Francisco, Cal.

BRENNER, Wm. H. (1897), 210 Simpson St., Atlanta, Ga.

BROWN, Edwin Hacker (Junior, 1903), Member of Firm, Hewitt & Brown, 716 Fourth Ave., S., and 2303 Pleasant Ave., Minneapolis, Minn.

BROWN, Walter Ellsworth (Junior, 1910), Asst. Engr. and Supt., Penn Motor, Car Co., 7510 Thomas Blvd., Pittsburg, Pa.

BRYAN, William H. (1891), Cons. Mech. and Elec. Engr., 418–419 Title Guaranty Bldg., and 5718 Vernon Ave., St. Louis, Mo.

BURGESS, A. Bradley (Junior, 1901), Engr., Standard Plunger Elev. Co., Worcester, Mass.

CARLE, Nathaniel A. (1907), Cons. and Contr. Engr., 709 Central Bldg., Seattle, Wash.

COLLIER, Wm. H. (1901; 1904), Mgr., So. Motor Wks., Nashville, Tenn.

COLWELL, James V. V. (1903), Life Member; Mgr. N. E. Dept., Heine Safety Boiler Co., Rm. 302, 201 Devonshire St., Boston, Mass., and 1765 Sedgwick Ave., New York, N. Y.

COOK, John P. (Junior, 1906), 31 Garfield Pl., Albany, N. Y.

COON, Thurlow E. (Junior, 1908), Partner, Coon-DeVisser Co., 1801 Ford Bldg., and 55 Leicester Court, Detroit, Mich.

DURANT, Aldrich (Junior, 1906), 120 E. 31st St., New York, N. Y., and 9 Lowell St., Cambridge, Mass.

ENGLISH, William T. (1902), Pres., Walworth-English-Flett Co., 100 Pearl St., Boston, and 185 W. River St., Hyde Park, Mass.

FIEUX, Ernest D. (Junior, 1907), Pres. and Treas., L. J. Wing Mfg. Co., 90 West St., New York, and *for mail*, Commonwealth Ave., Chester Hill Park, Mt. Vernon. N. Y.

GAEHR, David (1902; 1909), Contr. Engr., 950–952 Rockefeller Bldg., and 2626 E. 75th St., Cleveland, O.

GAMPER, Herman (1900), Supt., Munic, Ltg. Dept., and *for mail*, 377 W. 9th Ave., Columbus, O.

GORE, Warren W. (1908), Exper. Engr., Fairbanks, Morse Mfg. Co., and *for mail*, 911 Harrison Ave., Beloit, Wis.

GREENE, Augustine E. (1909), Mill Engr., 60 Prospect St., Hartford, Conn.

GUY, Albert Emile (1905),Mech. Engr., E. Hamilton Ave., R. F. D. 3, Trenton, N. J.

HARTER, Isaac, Jr. (Associate, 1908), Babcock & Wilcox Co., Bayonne, N. J.

HEALY, Frederick E. (1906), Mech. Engr. and Spec. Agt., Alberene Stone Co., New York, N. Y., and *for mail*, 1350 Monroe St., N. W., Washington, D. C.

HEISLER, Charles L. (1895), 323 Glenwood Blvd., Schenectady, N.Y.

HERBERT, Jack Stanley (1908), V. P. and Ch. Engr., Penn Motor Car Co., 7510 Thomas Blvd., Pittsburg, Pa.

HIGGINS, Albert W. (Associate, 1906), 106 Wenham Ave., Grand Rapids, Mich.

HOFMEYER, George August (Associate, 1905), Cons. Engr., 207 W. 24th St., and *for mail*, 145 W. 16th St., New York, N. Y.

HOLLOWAY, Thurman Welford (Junior, 1906), Internatl. Corr. Schools, Ltd., Scranton, Pa.

HOWARD, Chas. Alton (Junior, 1907), Mech. Engr., Gunn, Richards & Co., 43 Wall St., New York, N. Y.

HURD, Charles Henry (1902), Mech. and Hyd. Engr., 113 Monument Pl., Indianapolis, Ind.

HURLEY, Daniel (Junior, 1904), Watertown Arsenal, Watertown, Mass., and 42 E. Manning St., Providence, R. I.

JAQUAYS, Homer Morton (1899; 1903), Montreal Rolling Mill Co., 3106 Notre Dame St., Montreal, and *for mail*, 645 Grosvenor Ave., Westmount, P. Q., Canada.

JOHNSON, Warren (Associate, 1904), Cons. Engr., 122 Carondelet St., and 6209 Howard St., New Orleans, La.

JURGENSEN, Jess Christian (Associate, 1905), 114 Main St., Hackensack, N. J.

KENNEDY, William A. (Junior, 1908), Testing Engr., Genl. Fire Extinguisher Co., and *for mail*, 31 Forest St., Providence, R. I.

KEYES, Frederic H. (1902), 88 Broad St., Boston, Mass.

KING, W. Grant (1894; 1904), V. P. and Genl. Mgr., King Sewing Mch. Co., 90 Welland St., Buffalo, N. Y.

KUWADA, Gompei, (1900), Osaka Gas Co., Osaka, Japan.

LOUER, Lewis S. (Associate, 1900), Western Mgr., Engrg. Record, 1570 Old Colony Bldg., Chicago, Ill.

McCREERY, James Harold (Junior, 1910), 802 Atlantic Bldg., 49 Wall St., New York, N. Y., and *for mail*, 415 W. 7th St., Plainfield, N. J.

McMULLIN, Frank V. (1903), United Eng. & Fdy. Co., 2313 Farmers Bank Bldg., Pittsburg, Pa.

MacGILL, Charles Frederick (1896), 1489 Minnehaha Ave., St. Paul, Minn.

MANLEY, Sumner Marshall (Junior, 1907), M. M., Proctor & Gamble Co., and *for mail*, 3616 Jefferson St., Kansas City, Mo.

MARSHALL, Stewart McCulloch (1907; 1910), Asst. Ch. Engr., Cambria Steel Co., and *for mail*, 134 Tioga St., Johnstown, Pa.

MARTENS, Ferdinand (1885), care Dr. H. Joachim, Hofweg 13, Hamburg, Germany.

MILLETT, Kenneth Ballard (Junior, 1908), Newburgh Ice Mch. & Eng. Co., and *for mail*, P. O. Box 243, Newburgh, N. Y.

MOULTHROP, Leslie (Associate, 1891), Receiver, Dwight Slate Mch. Co., and *for mail*, 620 Orange St., New Haven, Conn.

HULFELD, John E. (1908), V. P. and Genl. Mgr., Kansas City So. Ry., Thayer Bldg., Kansas City, Mo.

MULLER, Edward A. (1890), Secy. and Mgr., King Mch. Tool Co., Winton Pl., and *for mail*, 501 Mitchell Ave., Avondale, Cincinnati, O.

NELSON, Eric Hugo (1909), Ch. Draftsman, Geo F. Blake Mfg. Co., Cambridge and *for mail*, 15 Montague St., Arlington Hgts., Mass.

NEWCOMB, Robert Scott (Junior, 1909), Draftsman, Griscom-Spencer Co., Jersey City, and *for mail*, Palisade, N. J.

NORDMEYER, Louis C. (Junior, 1899), Secy. and Treas., Tait-Nordmeyer Engrg. Co., 1012 Liggett Bldg., and 4256 Shenandoah St., St. Louis, Mo.

PARKER, Levin S. (1908), Mech. Engr., Atlantic, Gulf & Pacific Co., 2407 Park Row Bldg., New York, and *for mail*, 1814 Ave. J., Flatbush, Brooklyn, N. Y.

PETTIS, Clifton D. (1905), Amer. Brake Shoe & Fdy. Co., 1414 McCormick Bldg., Chicago, Ill.

PITKIN, Arthur Frederick (Junior, 1907), Asst. Mech. Supt., Genl. Elec. Co., and 35 Waverly Pl., Schenectady, N. Y.

POMEROY, Harry D. (1892; 1904), 512 Dillaye Bldg., and 110 Baker Ave., Syracuse, N. Y.

PORTER, Hollis P. (1910), Ch. Engr. of Power, Cerro de Pasco Min. Co., La Fundicion, Peru, S. A.

PURINTON, Arthur James (1893), Genl. Supt., St. Joseph Ry., Light, Heat & Power Co., St. Joseph, Mo.

RATTLE, Paul S. (Junior, 1908), Charge of Pump and Compressor Dept., Mine & Smelter Supply Co., 17th and Blake Sts., Denver, Colo.

RAY, David H. (Associate, 1904), Ch. Engr., Bureau of Bldgs., Borough of Manhattan, 220 Fourth Ave., New York, N. Y.

RICHARDS, William A. (Junior, 1903), Charge of Mch. Shops, Forge and Fdy., Univ. H. S., Univ. of Chicago, Chicago, Ill.

SAR VANT, Wilbur Nason (Junior, 1907), Asst. Ch. Engr., Standard Turpentine Co. of Fla., 1016 Atlantic Natl. Bank Bldg., and *for mail*, 29 W. Monroe St., Jacksonville, Fla.

SELLEW, Ernest B. (Associate, 1907), Pres. and Mgr., Sellew Mch. Tool Co. Pawtucket, R. I.

SHERMAN, W. D. (1907), Huston Concrete Co., Zulueta 46, Havana, Cuba.

SLAUSON, Harold W. (Junior, 1908), Assoc. Editor, Recreation, 24 W. 39th St., New York, and *for mail*, cor. S. Broadway and Post St., Yonkers, N. Y.

SMITH, Allen C. (1902), Ch. Mech. Designer, Ottis Elev. Co., Yonkers, N. Y.

SMITH, Charles P. (Junior, 1888), Lower Pacific Mills, and *for mail*, 48 Olive Ave., Lawrence, Mass.

SMITH, Roy B. (Junior, 1905), Inspr., Pa. Lines West, and *for mail*, The Normandie, Columbus, O.

SMITH, William E. (Junior, 1908), Babcock & Wilcox Co., and *for mail*, 421 W. Lake Ave., Barberton, O.

STUTZ, C. C. (1900), Cons. Engr., Amer. Cement Tile Mfg. Co., Rm. 1309, 29 Broadway, New York, N. Y.

SUTER, Geo. A. (1883; 1893), 112 Wooster St., and *for mail*, 190 Riverside Drive, New York, N. Y.

SYMINGTON, E. Harrison (Associate, 1903), Mech. Expt., T. H. Symington Co., 616 Ry. Exch., Chicago, Ill.

TAIT, Roderick H. (1904), Pres., Tait-Nordmeyer Engrg. Co., 1012 Liggett Bldg., and 1368 Granville Pl., St. Louis, Mo.

TWINING, Wm. S. (1897), Ford, Bacon & Davis, 115 Broadway, New York, N. Y.

ULBRICHT, T. Carlile (Junior, 1908), Instr., Dept. of Power Engrg., Sibley College, Cornell Univ., and *for mail*, 426 E. Buffalo St., Ithaca, N. Y.

VAN VALKENBURGH, Ralph D. (1901; Associate, 1905), Engrg. Salesman, Taylor Iron & Steel Co., High Bridge, N. J., and *for mail*, 1602 Jefferson Ave., Scranton, Pa.

WALSH, Thomas J. (Junior, 1906), Stone & Webster Engrg. Corp., Boston, Mass., and *for mail*, 97 Howard Ave., Ansonia, Conn.

WEISSBLATT, Murray E. (Junior, 1907), Crocker-Wheeler Co., 1315 North Amer. Bldg., Philadelphia, Pa.

WHITE, James A. (Junior, 1900), Worcester Pressed Steel Co., and *for mail*. 167 Lincoln St., Worcester, Mass.

WILLIAMS, Alan Gillespie (Junior, 1909), Genl. Foreman, in charge Buffalo Shops, Pa. R. R., and *for mail*, 17 Johnson Park, Buffalo, N. Y.

WILLISTON, Arthur L. (1896; 1899), 27 Kilsyth Rd., Brookline, Mass.

WINSHIP, W. E. (1908), cor. 177th St. and Pinehurst Ave., New York, N. Y.

ZOWSKI-ZWIERZCHOWSKI, S. J. (1910), Asst. Prof. Mech. Engrg., Univ. of Mich., and *for mail*, 1304 Geddes Ave., Ann Arbor, Mich.

NEW MEMBERS

BARRON, Claude Mitchell (Junior, 1910), with R. W. Wiggin, Apartado 97-B, Mexico City, Mex.

CORLETTE, Glen H. (Junior, 1910), Fairbanks, Morse & Co., 566 Calle Moreno Buenos Aires, Argentine Republic, S. A.

LORING, Harrison, Jr. (1910), Treas. and Mech. Engr., R. S. Brine Transportation Co., 43 India St., Boston, Mass.

SAYER, Eugene Young (1910), V. P. and Genl. Mgr., Improved Equipment, Co., 60 Wall St., New York, N. Y.
SHAW, Joseph D. (1910), Cons. Engr., Partner, Fountain-Shaw Engrg. Co., 308 Andrews Bldg., Dallas, Tex.
VAN PATTEN, William Ensign (1910), Superintending Power and Light Plants, M. & E. Div., D. L. & W. R. R., Hoboken, and *for mail*, 48 Lunan Pl., Jersey City, N. J.
WIGGIN, Ralph Mitchell (1910), Apartado 97-B, Mexico City, Mex.
WYATT, Edgar William (1910), Cons. Engr., 632 Marlborough Rd., Brooklyn, N. Y.

DEATHS

JOHNSON, Lewis, May 26, 1910.
HALL, Frederick Bellows, October 27, 1910.
ROBINSON, Stillman W., October 31, 1910.
SHANTZ, Oliver S., September 1910.

GAS POWER SECTION

CHANGES OF ADDRESS

COLWELL, James V. V. (1908), Mem.Am.Soc.M.E.
GORE,, Warren W. (1909), Mem.Am.Soc.M.E.
HOWARD, Charles A. (1908), Mem.Am.Soc.M.E.
McMULLIN, Frank V. (1908), Mem.Am.Soc.M.E.
ULBRICHT, T. C. (1908), Mem.Am.Soc.M.E.
WINSHIP, W. E. (1909), Mem.Am.Soc.M.E.

STUDENT MEMBERSHIP

BERGERT, H. A. (Student, 1910), care C. R. I. & P. R. R. Shop, Silvis, Ill.
BOHNSTENGEL, Walter (Student, 1909), 1111 Kentucky St., Lawrence, Kan.
BUTLER, N. R. (Student, 1909), 1600 Madison Ave., Baltimore, Md.
CARR, W. deL. (Student, 1909), 32 Vine St., West Lynn, Mass.
CUMPSTON, E. H., Jr. (Student, 1909), 2727 P St., Washington, D. C.
ESTES, G. H. (Student, 1910), 112 Newbery St., Boston, Mass.
GRIFFITH, F. H. (Student, 1909), 41 W. 33d St., Chicago, Ill.
GRAY, C. F. (Student, 1910), 333 W. Washington St., Madison,Wis.
KELLEY, P. W. (Student, 1910), 1254 Michigan Ave., Chicago, Ill.
KONSTANKEWICZ, M. J. (Student, 1910), 303 N. Shamokin St., Shamokin, Pa.
KRAATZ, K. L. (Student, 1910), 224 N. Brooks St., Madison, Wis.
McCAIN, W. R. (Student, 1910), present address unknown.
MATTERN, J. Fred. (Student, 1910), University Club, Altoona, Pa.
MORGAN, Henry (Student, 1910), 2533 N. Grand Ave., St. Louis, Mo.
MUFFLY, Walter W. (Student, 1910), Hotel Morgan, South Sharon, Pa.
NELSON, J. E. (Student, 1909), East Ryegate, Vt.
OAKLEY, Walter W. (Student, 1910), 502 N. Market St., Kokomo, Ind.
PARMELY, J. C. (Student, 1909), 128 Smith St., Kewanee, Ill.
PAUL, Harry J. (Student, 1910), 930 Roscoe St., Chicago, Ill.
PIMPER, T. F. (Student, 1910), 1302 30th St., Washinton, D. C.
PURDY, Donald F. (Student, 1910), 157 N. 20th St., Philadelphia, Pa.
RICHEY, A. L. (Student, 1909), 915 E. State St., Ithaca, N. Y.
RUSSELL, Foster (Student, 1910), 39 Cumberland St., Boston, Mass.
SCHUSTER, George (Student, 1909), 905 Fourth Ave., Rock Island, Ill.
STEINBECK, C. E. (Student, 1909), Burlingame, Cal.
WEAVER, H. E. (Student, 1910), 208 S. 10th St., Columbia, Mo.
YODER, Jacob H. (Student, 1910), Sch. for Apprentices, 1120 13th Ave., Altoona, Pa.

NEW MEMBERS

BROOKLYN POLYTECHNIC INSTITUTE

WICHUM, Victor (Student, 1910), 241 Covert St., Brooklyn, N. Y.

COLUMBIA UNIVERSITY

CLARK, S. M. (Student, 1910), 427 Franklin Ave., Brooklyn, N. Y.
FREDERICHS, W. (Student, 1910), 53 Lewis St., Tompkinsville, S. I., N. Y.
HENDRICKSON, M. E. (Student, 1810), 536 Dean St., Brooklyn, N. Y.

MURPHY, E. A. (Student, 1910), Livingston Hall, Columbia Univ., New York, N. Y.
RILEY, W. L. (Student, 1910), 614 W. 113th St., New York, N. Y.
SELLEW, W. H. (Student, 1910), 78 E. 79th St., New York, N. Y.

CORNELL UNIVERSITY

BELLINGER, E. W. (Student, 1910), 201 Oak Ave., Ithaca, N. Y.
BOGARDUS, A. G. (Student, 1910), 6 South Ave., Ithaca, N. Y.
HOLDEN, R. O. (Student, 1910), 133 Linden Ave., Ithaca , N. Y.
OVEROCKER, R. H. (Student, 1910), 109 College Ave., Ithaca, N. Y.
TRUMP, C. C. (Student, 1910), 103 Highland Pl., Ithaca, N. Y.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

BESSE, E. E. (Student, 1910), 39 Cumberland St., Boston, Mass.
BROWNLEE, Robt. B. (Student, 1910), 38 St. Botolph St., Boston, Mass.
BURLEIGH, W. S. (Student, 1910), 107 W. Central St., Natick, Mass.
FERRY, Ralph M. (Student, 1910), 134 W. Newton St., Boston, Mass.
MEISEL, O. C. F. (Student, 1910), 10 Upland Ave., Dorchester, Mass.

UNIVERSITY OF ILLINOIS

ALLEN, G. B. (Student, 1910), 706 S. 2d St., Champaign, Ill.
CONNARD, A. F. (Student, 1910), 908 S. 5th St., Champaign, Ill.
DUTT, M. L. (Student, 1910), 1012 W. Oregon St., Urbana, Ill.
FAISON, Wm. A. (Student, 1910), 212 E. Green St., Champaign, Ill.
HAGEDORN, F. A. (Student, 1910), 706 S. 2d St., Champaign, Ill.
HASSELQUIST, E. J. (Student, 1910), 934 W. Illinois St., Urbana, Ill.
HERRCKE, E. A. (Student, 1910), 706 S. 2d St., Champaign, Ill.
KNAUSS, (Student, 1910), 805 W. Illinois St., Urbana, Ill.
PHILLEO, G. W. (Student, 1910), 1107 Springfield Ave., Urbana, Ill.
STUEBING, A. F. (Student, 1910), 311 E. Healy St., Champaign, Ill.
WHITNALL, C. A. (Student, 1910), 1002 S. 6th St., Champaign, Ill.

YALE UNIVERSITY

BAKER, F. H. (Student, 1910), 133 Wall St., New Haven, Conn.
BORKETT, D. B. (Student, 1910), Byers Hall, New Haven, Conn.
BRADY, G. S. (Student, 1910), 872 Yale P. O., New Haven, Conn.
COOK, H. J. (Student, 1910), 70 Trumbull St., New Haven, Conn.
DEMAREST, L. McG. (Student, 1910), 166 Sheff. Vanderbilt, New Haven, Conn.
DRAVO, H. D. (Student, 1910), 164 Sheff. Vanderbilt, New Haven, Conn.
DuBOSQUE, C. (Student, 1910), 166 Sheff. Vanderbilt, New Haven, Conn.
GRAFF, W. (Student, 1910), 246 Dwight St., New Haven, Conn.
HAYES, H. E. (Student, 1910), 148 Grove St., New Haven, Conn.
JOHNSON, D. A. (Student, 1910), 177 Sheff. Vanderbilt, New Haven, Conn.

JONES, M. F. (Student), 1910, 96 Wall St., New Haven, Conn.
KELLY, R. A. (Student, 1910), Temple St., New Haven, Conn.
KNABLE, G. E. (Student, 1910), 124 Prospect St., New Haven, Conn.
MANNY, W. R. (Student, 1910), 166 Sheff. Vanderbilt, New Haven, Conn.
MEEKER, L. A. (Student, 1910), 167 Sheff. Vanderbilt, New Haven, Conn.
MILLS, C. G. (Student, 1910), 124 Prospect St., New Haven, Conn.
PERLEY, A. D. (Student, 1910), Byers Hall, New Haven, Conn.
PRUDDEN, J. M. (Student, 1910), Byers Hall, New Haven, Conn.
REEVE, A. B. (Student, 1910), Byers Hall, New Haven, Conn.
RUGE, J. H. (Student, 1910), 746 Yale Sta., New Haven, Conn.
WATZEK, J. W. (Student, 1910), Byers Hall, New Haven, Conn.

COMING MEETINGS

DECEMBER—JANUARY

Advance notices of annual and semi-annual meetings of engineering societies are regularly published under this heading and secretaries or members of societies whose meetings are of interest to engineers are invited to send such notices for publication. They should be in the editor's hands by the 15th of the month preceding the meeting. When the titles of papers read at monthly meetings are furnished they will also be published.

THE AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE

December 27–January 3, Minneapolis and St. Paul, Minn. Secy., L. O. Howard, Smithsonian Institution, Washington, D. C.

AMERICAN CHEMICAL SOCIETY

December 27–30, meeting with the American Association for the Advancement of Science, Minneapolis, Minn. Secy., Charles L. Parsons, Durham, N. H.

THE AMERICAN INSTITUTE OF ARCHITECTS

January 17–19, annual convention, San Francisco, Cal. Papers: The Development of Architecture on the Pacific Coast and the Rehabilitation of the City of San Francisco, The Aesthetic Problems of and what the Coast has Accomplished in City Planning, The Salient Points of the Architecture of the Northern Pacific Coast, by Chas. H. Bebb; History and Present Status of the California Missions, by A. B. Benton. Secy., Glenn Brown, The Octagon, Washington, D. C.

AMERICAN INSTITUTE OF CHEMICAL ENGINEERS

December 7–10, annual meeting, New York. Papers: Chemical Engineering Education, F. W. Frerichs, F. W. Atkinson, M. C. Whitaker; The Fitzgibbons Boiler, Jerome Alexander; Manufacture of Hydrated Lime, Richard K. Meade; The Evolution of Portland Cement Processes, Chas. F. McKenna; Manufacture of Lignite Briquettes, Henry S. Renaud; Bleaching Oils with Fullers Earth, David Wesson; Action of Fruit Juices on Metallic Containers, E. Gudeman; Vacuum Distilling Apparatus, P. B. Sadtler; Symposium on Sewerage Disposal, Geo. C. Whipple, R. Hering, Mem.Am.Soc.M.E., Geo. A. Soper, N. S. Hill, Jr., Chas. E. A.Winslow. Secy., J. C. Olsen, Polytechnic Institute, Brooklyn, N. Y.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

January 13, 29 W. 39th St., New York. Secy., R. W. Pope.

AMERICAN MATHEMATICAL SOCIETY

December 28–29, Columbia University, New York; December 29–30, University of Chicago ,Chicago, Ill. Secy., F. N. Cole, 501 W. 116th St., New York.

AMERICAN SOCIETY OF CIVIL ENGINEERS

January 18–19, annual meeting, 220 W. 57th St., New York. Secy., C. W. Hunt.

AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS

January 24–26, annual meeting, 29 W. 39th St., New York. Secy., W. M Mackay, Box 1818.

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS

December 6–9, annual meeting, 29 W. 39th St., New York. December 23, joint meeting with the American Institute of Electrical Engineers, Boston, Mass. Secy., Calvin W. Rice.

AMERICAN SOCIETY OF REFRIGERATING ENGINEERS

December 5–6, annual meeting, New York. Secy., W. H. Ross, 154 Nassau St.

ASSOCIATION OF AMERICAN PORTLAND CEMENT MANUFACTURERS

December 12–14, annual convention, New York. Secy.,Percy H.Wilson, Land Title Building, Philadelphia, Pa.

AUTOMOBILE EXPOSITION

December 31–January 7, Grand Central Palace, New York. Secy., B. Briscoe, 7 E. 42d St.

BROOKLYN ENGINEERS CLUB

December 1, 117 Remsen St., Brooklyn, N. Y. Paper: The Gyroscope, Elmer A. Sperry. Secy., Joseph Strachan.

CIVIL ENGINEERS SOCIETY OF ST. PAUL

January 9, annual meeting, Old State Capitol Bldg., St. Paul, Minn. Secy., D. F. Jurgensen, 116 Winter St.

ELECTRICAL CONTRACTORS ASSOCIATION OF NEW YORK STATE

January 10, ex-semi annual meeting, Albany, N. Y. Secy., Geo. W. Russell, Jr., 25 W. 42d St., New York.

ENGINEERS' CLUB OF ST. LOUIS

December 7, annual meeting, 3817 Olive St., St. Louis, Mo. Secy., W. W. Homer, 5203 Maple Ave.

ENGINEERS SOCIETY OF PENNSYLVANIA

January 16, annual meeting ,Harrisburg, Pa. Secy., Edw. R. Dasher, Gilbert Bldg.

ENGINEERS SOCIETY OF WESTERN PENNSYLVANIA

January 17, annual meeting, Oliver Bldg., Pittsburg, Pa. Secy., E. K. Hiles, 803 Fulton Bldg.

ILLINOIS SOCIETY OF ENGINEERS AND SURVEYORS

January 25–27, annual meeting, East St. Louis, Ill. Secy., E. E. R. Tratman. 1636 Monadnock Blk., Chicago, Ill.

INDIANA ENGINEERING SOCIETY

January 12–14, annual meeting, Indianapolis, Ind. Secy., Chas. Brossman.

NATIONAL ASSOCIATION OF CEMENT USERS

December 12–20, annual convention, Concert Hall, Madison Square Garden, New York. President Richard L. Humphrey, Harrison Bldg., Philadelphia, Pa.

THE NATIONAL CIVIC FEDERATION

January 12–14, annual meeting, Hotel Astor, New York. Chairman Executive Council, Ralph M. Easley, 1 Madison Ave.

NATIONAL COMMERCIAL GAS ASSOCIATION

December 5–13, annual convention, Boston, Mass. Pres., L. S. Bigelow, 1374 Main St., Buffalo, N. Y.

NATIONAL GAS AND GASOLINE ENGINE TRADES ASSOCIATION

December 12–15, annual meeting, Racine, Wis. Secy., A. Stritmatter, Cincinnati, O.

NEW ENGLAND RAILROAD CLUB

December 13, New American House, Boston, Mass. Paper: The evolution of Air Brakes Made Necessary to meet modern Train Conditions, H. N. Lamb. Secy., Geo. H. Frazier, 10 Oliver St.

NEW JERSEY SANITARY ASSOCIATION

December 2–3, annual meeting, Lakewood, N. J. Papers; Two Years' Experience in Dust Suppression on Roads, James Owen; Latest Phases of Sewage Purification, Rudolph Hering, Mem.Am.Soc.M.E.; The Possible Deleterious Effects of Illuminating Gas upon the Human Economy and the Probable Extent to which they obtain, C. E. Forstall. Secy., J. A. Exton, 75 Beech St., Arlington.

SHORT LINE RAILROAD ASSOCIATION

December 15, annual meeting. Secy., John N. Drake, 60 Wall St., New York.

SOCIETY OF AUTOMOBILE ENGINEERS

January 11–12, annual meeting, New York. Pres., Howard E. Coffin, 1451 Broadway.

MEETINGS IN THE ENGINEERING SOCIETIES BUILDING

Date	Society	Secretary	Time
1	Blue Room Engineering Society	W. D. Sprague	8.15 p.m.
6, 7, 8, 9	American Society Mechanical Engineers	C. W. Rice	All day
7	Wireless Institute	S. L. Williams	8.00 p.m.
8	Illuminating Engineering Society	P. S. Millar	8.15 p.m.
9	American Institute Electrical Engineers	R. W. Pope	8.00 p.m.
16	New York Railroad Club	H. D. Vought	8.15 p.m.
20	New York Telephone Society	T. H. Lawrence	8.15 p.m.
28	Municipal Engineers of New York	C. D. Pollock	8.15 p.m.
January			
4	Wireless Institute	S. Williams	7.30 p.m.
5	Blue Room Engineering Society	W. D. Sprague	8.15 p.m.
10	American Society Mechanical Engineers	C. W. Rice	8.15 p.m.
12	Illuminating Engineering Society	P. S. Millar	8.15 p.m.
13	American Institute Electrical Engineers	R. W. Pope	8.15 p.m.
17	New York Telephone Society	T. H. Lawrence	8.15 p.m.
20	New York Railroad Club	H. D. Vought	8.15 p.m.
24, 25, 26	American Society of Heating and Ventilating Engineers	W. M. Mackay	All day
25	Municipal Engineers of New York	C. D. Pollock	8.15 p.m.

CURRENT BOOKS

THE HISTORY OF THE TELEPHONE. By Herbert N. Casson. *Chicago, A. C. McClurg Co., 1910.* Cloth, 8vo, 316 pp., fully illustrated. Price, $1.50.

Contents: The Birth of the Telephone; The Building of the Business; The Holding of the Business; The Development of the Art; The Expansion of the Business; Notable Users of the Telephone; The Telephone and National Efficiency; The Telephone in Foreign Countries; The Future of the Telephone; Index.

COMPOSITION AND HEAT TREATMENT OF STEEL. By E. F. Lake. *New York, McGraw-Hill Book Co., 1910.* Cloth, 12 vo, illustrated. Price $2.50.

Contents: The Making of Pig Iron; Bessemer Process of Converting Iron into Steel; Open-Hearth Process for Making Steel: Crucible Process of Steel Making; Electric Furnaces for Steel Making; Ingredients of and Materials used in Steel; Working Steel into Shape; Furnaces and Fuels used for Heat-Treatment; Annealing Steel; Hardening Steel; Tempering Steel; Carbonizing.

A TEXT-BOOK OF ELEMENTARY FOUNDRY PRACTICE. For the Use of Students in Colleges and Secondary Schools. By William Allyn Richards. *New York, The Macmillan Company, 1910.* Cloth, 8vo. 121 pp. Price, $1.25 net.

Contents: Introduction; Definition; Materials; Tools; Principles of Molding; Molding Exercises without Core; Matches; Molding Exercises with Green-Sand Cores; Dry Cores; Molding Exercises with Dry Cores; Miscellaneous Exercises; Open Molding, Sweep and Strike Work; Dry-Sand Molding; Cupola Practice or Melting; Cleaning Castings; Chilled and Malleable Castings; Brass Molding; Glossary; Appendix; Index.

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Univ. of Missouri, Columbia, Mo.	December 7	H. Wade Hibbard	H. W. Price	Osmer Edgar
Univ. of Nebraska, Lincoln, Neb.	December 7	C. R. Richards	W. J. Wholenberg	W. H. Burleigh
	1910			
Univ. of Maine, Orono, Me.	February 8	Arthur C. Jewett	H. N Danforth	A. H. Blaisdell
Univ. of Arkansas, Fayetteville, Ark.	April 12	B. N. Wilson	C. B. Boles	W. Q. Williams
Yale University, New Haven, Conn.	October 11			W. Roy Manny

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THE

JOURNAL

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS

CONTAINING
THE PROCEEDINGS

DECEMBER 1910

ANNUAL MEETING, NEW YORK, DECEMBER 6-9;
ST. LOUIS MEETING, DECEMBER 10;
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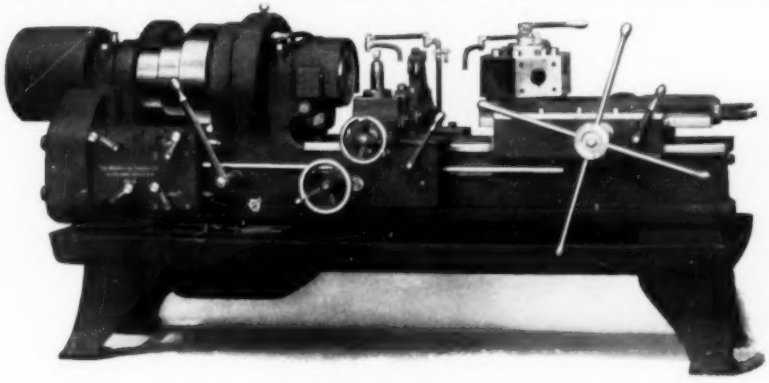

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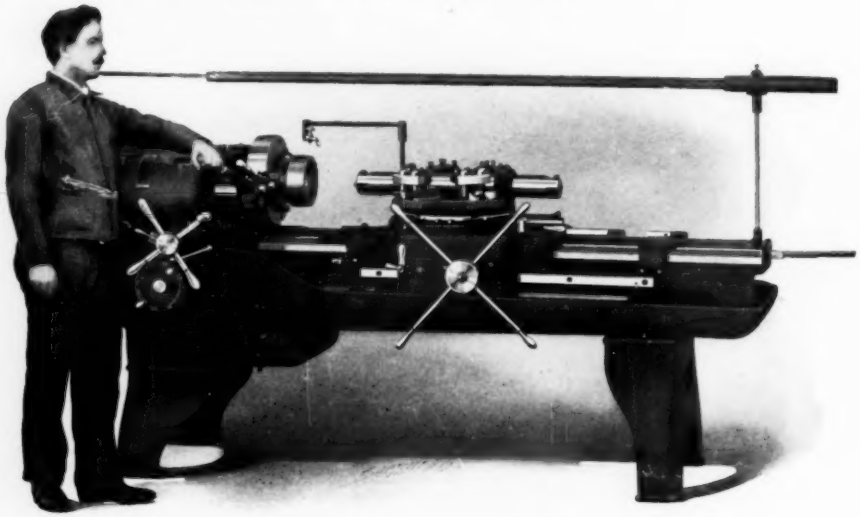

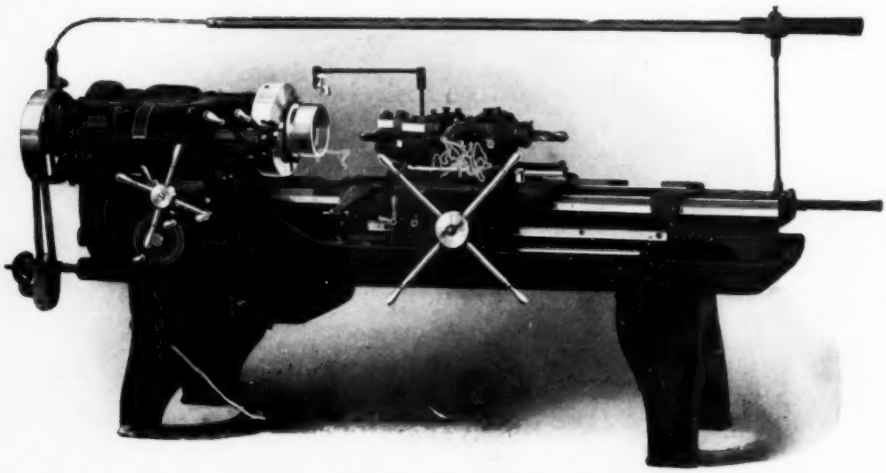

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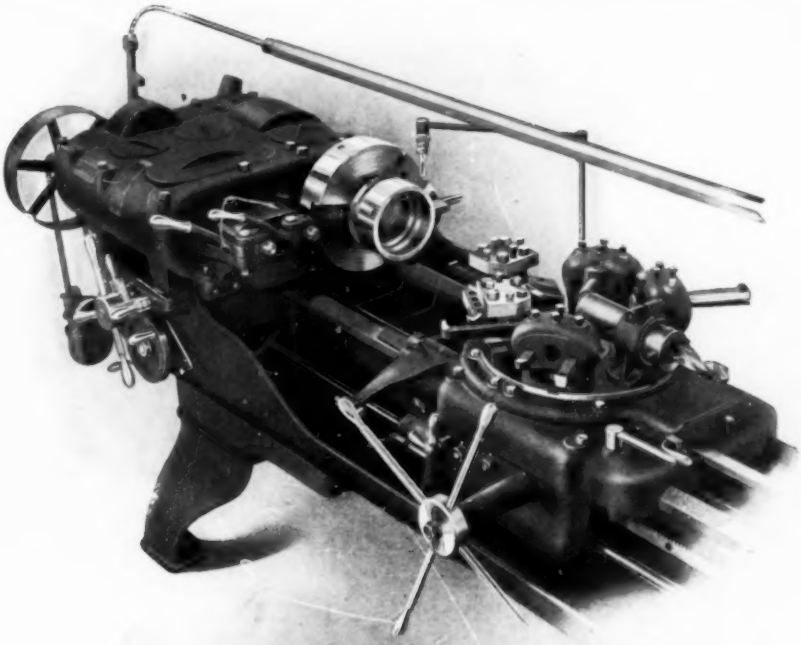

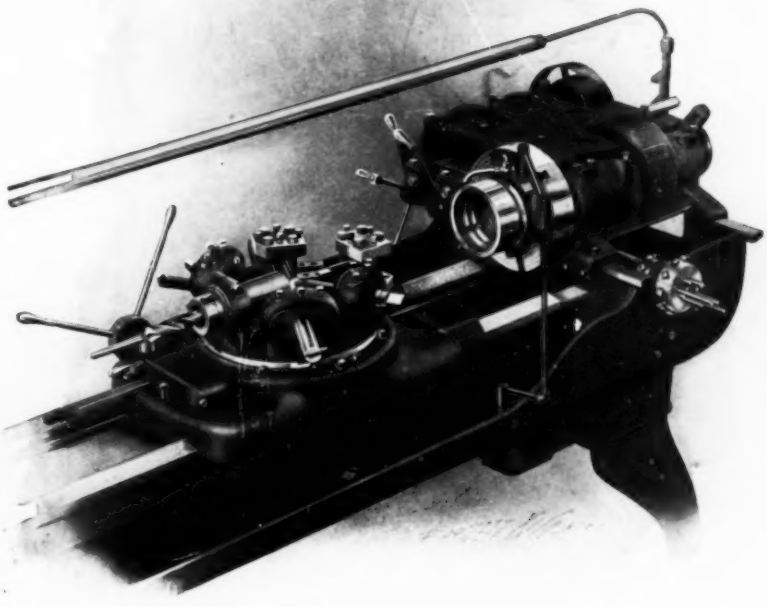

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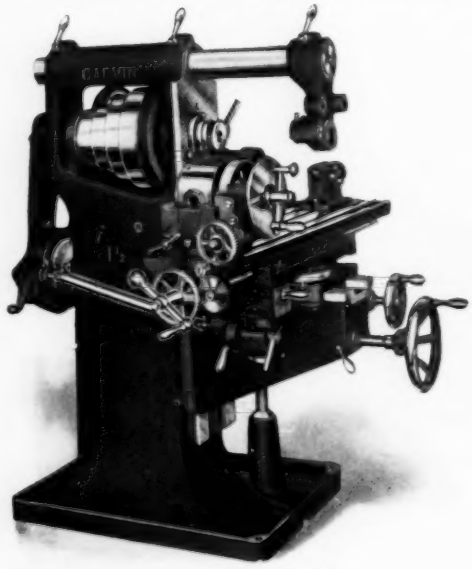

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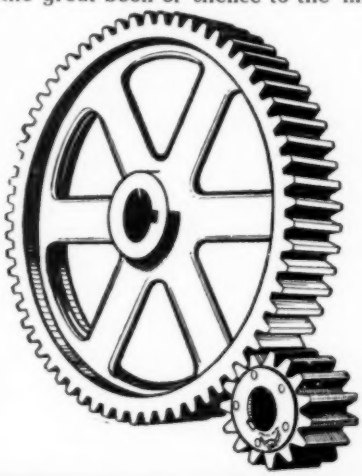

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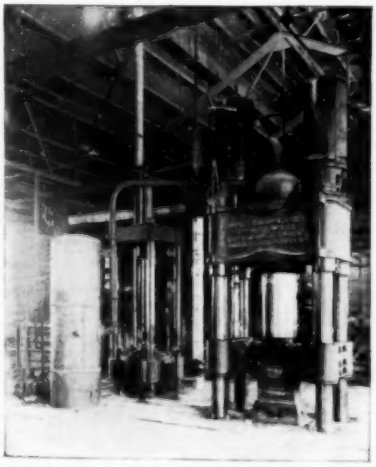

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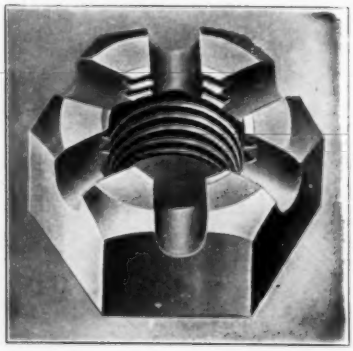

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THE NATIONAL MACHINERY CO TIFFIN, OHIO, U.S.A.

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SECTION 2

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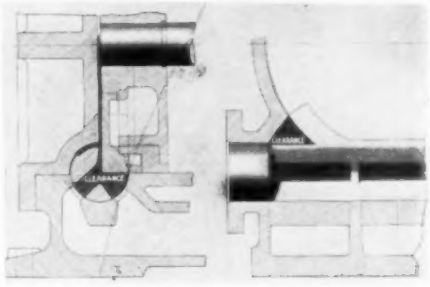
Machine Shop Equipment	Section 1
Power Plant Equipment	Section 2
Electrical Equipment	Section 3
Hoisting and Conveying Machinery. Power Transmission	Section 4
Engineering Miscellany	Section 5
Directory of Mechanical Equipment	Section 6



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It not only has less clearance than any other, but it has wider ports and much shorter steam passages. That means more power from the same size engine—with less steam.

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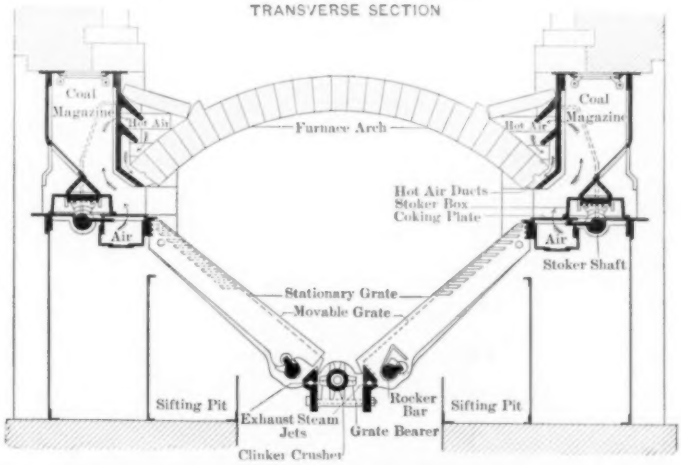

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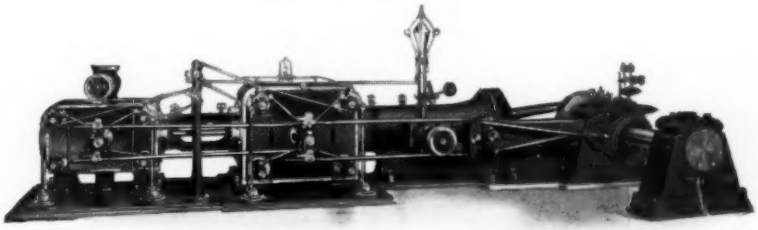

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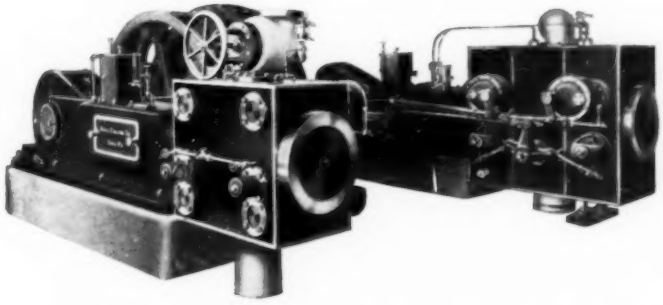

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This engine marks the extreme limit of excellence so far reached in economy and quiet running.

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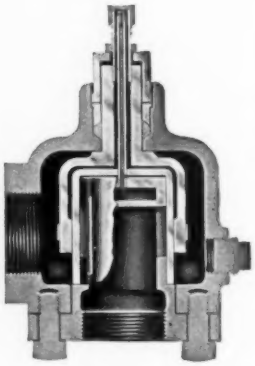

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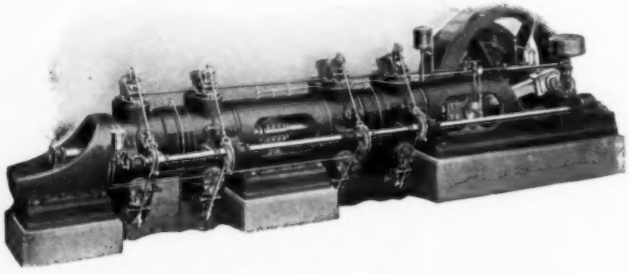

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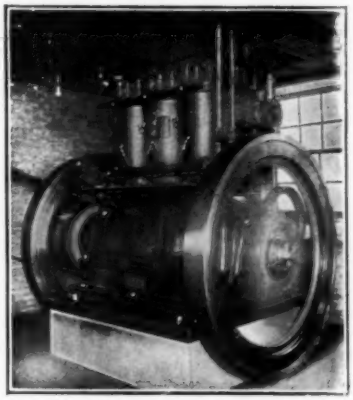

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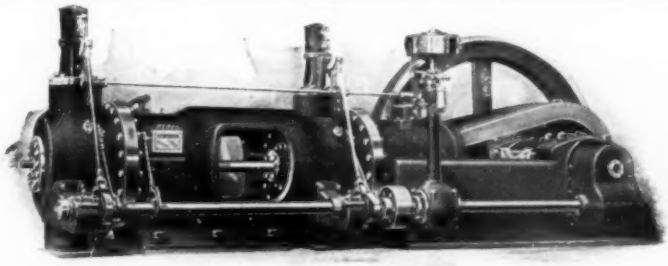

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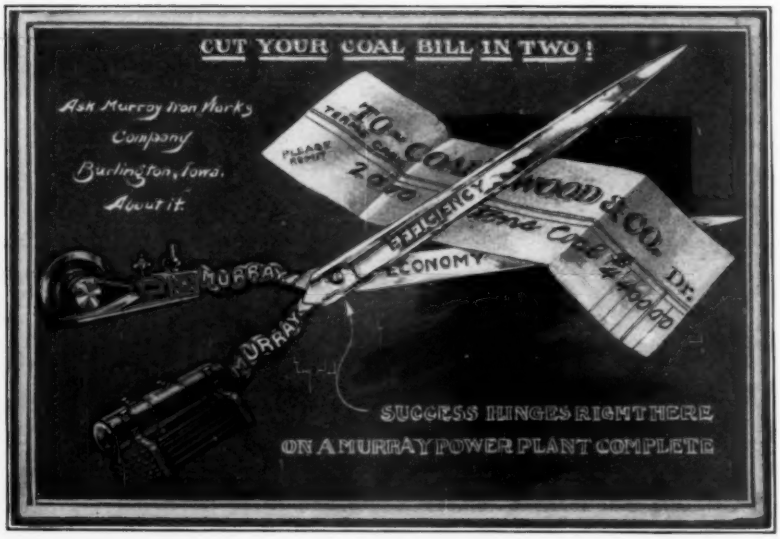
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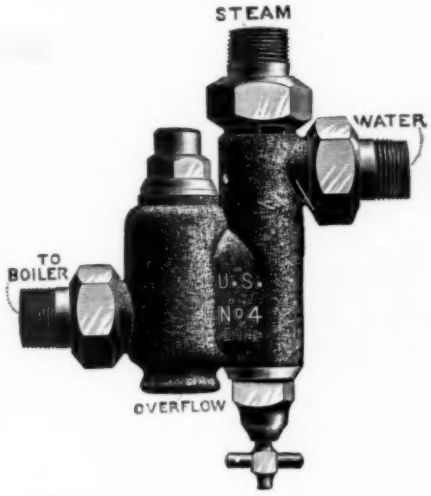

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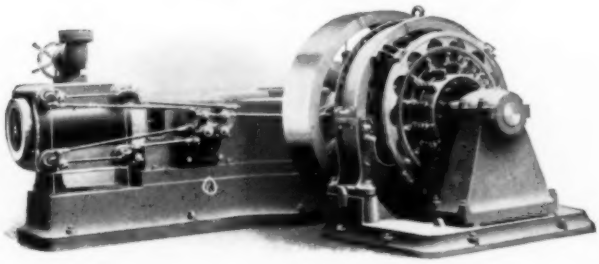

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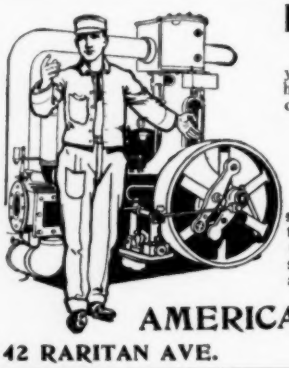

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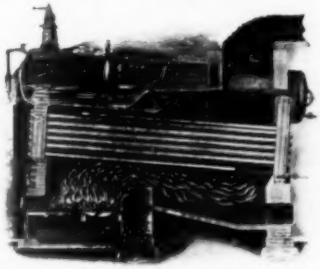

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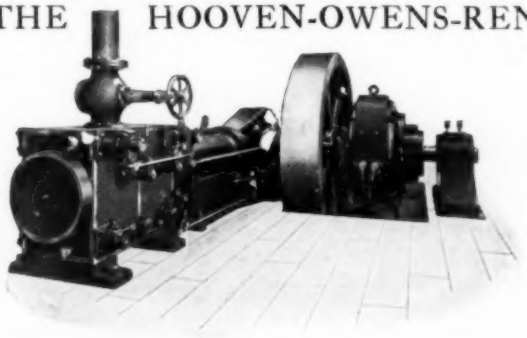

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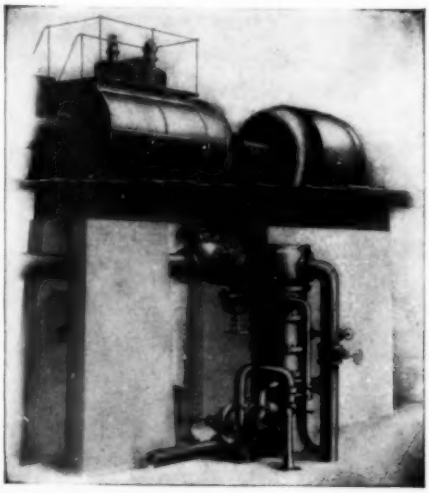

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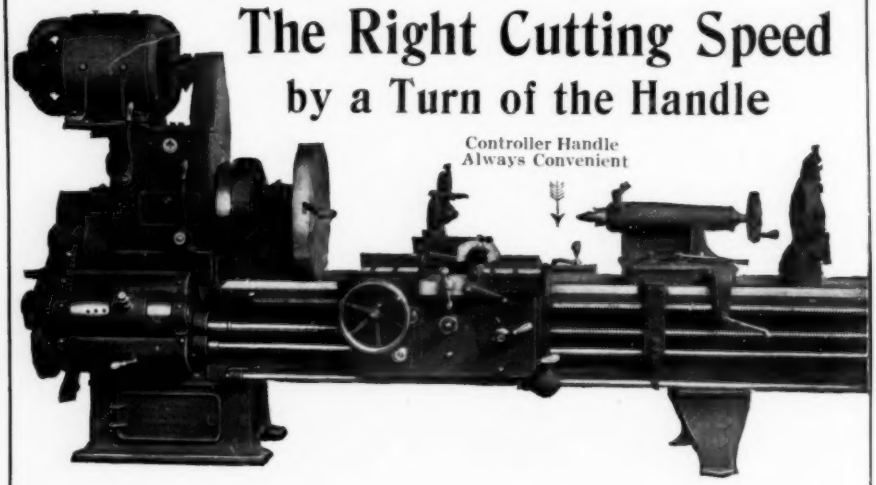

When installing a mechanical drive, the designing engineer sometimes knows the kind of work to be done and can select pulley diameters to approximate the best cutting speeds.

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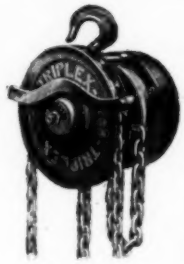

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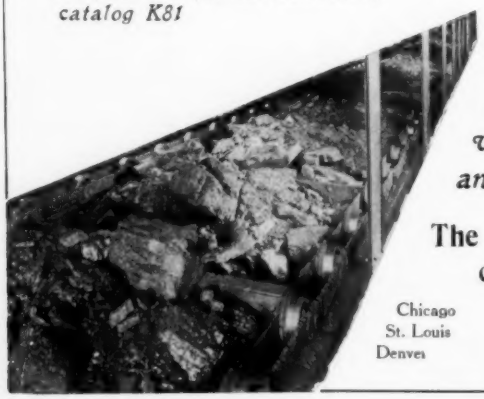

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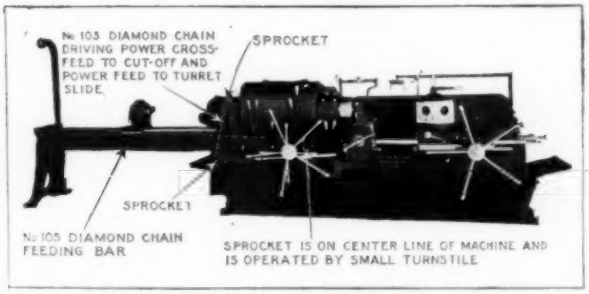
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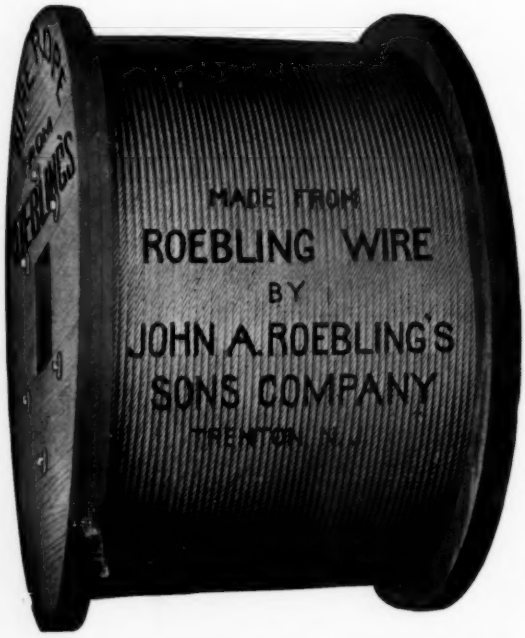

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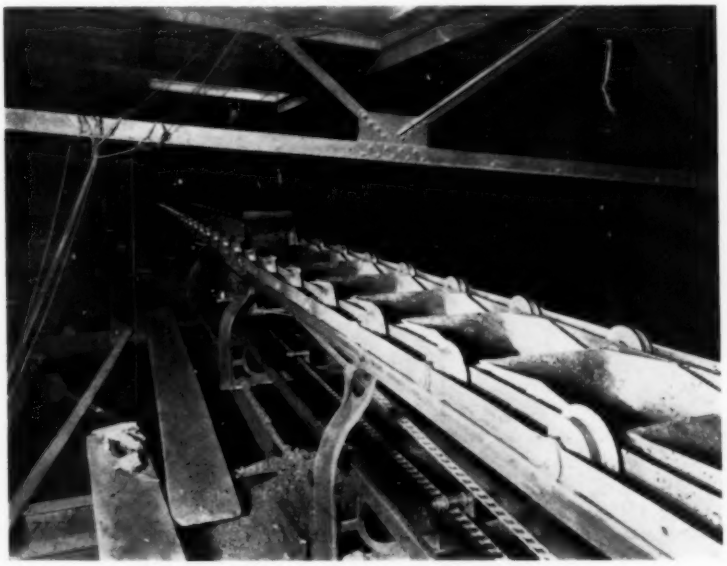

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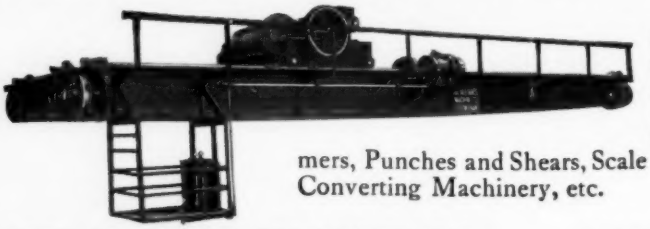

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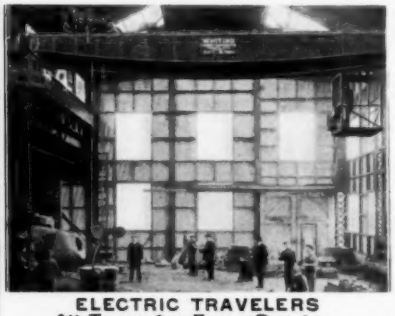

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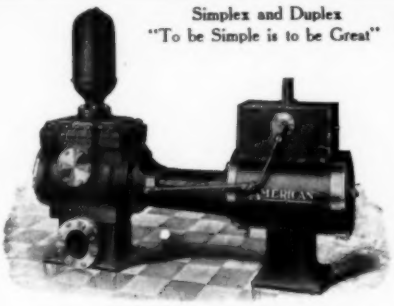

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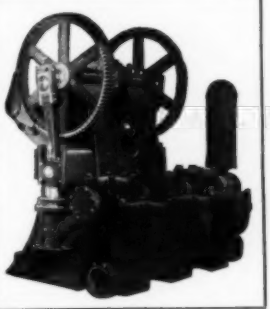

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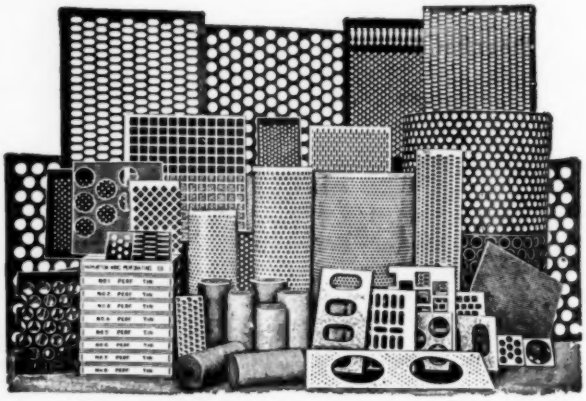

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